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DEMONSTRATION OF IRRIGATION RETURN FLOW WATER QUALITY CONTROL IN THE MESILLA VALLEY, NEW MEXICO

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16. ABSTRACT

A 182-ha operating farm was used to demonstrate the water pollution control benefits of implementing improved irrigation management techniques and structures. The commodity crops produced on the farm included wheat, tomatoes, cotton, lettuce, peppers, chiles, grain sorghum, and alfalfa. Improved water management in furrow, sprinkle, and trickle irrigation methods were evaluated. Economic analyses of alternative management practices were made for Mesilla Valley based on results from the demonstration farm. The use of irrigation scheduling could reduce irrigation return flows by 30 to 36% and salt loading by 38,000-42,000 tons annually. A combination of irrigation scheduling, sprinkler irrigation for germination and furrow irrigation for production gave the highest net returns to land and risk of all combinations assessed. In an 0.81 ha intensively monitored test plot area, the impact of changing irrigation efficiencies on residual soil solution salinity and salinity of drainage water was measured using cotton as the test crop. While there was a significant increase in soil salinity over the five-year test, yields increased 6% with 25% less water used by trickle application method as compared to conventional furrow methods.

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FOREWORD

Environmental protection efforts dealing with agricultural and other nonpoint sources have received increased emphasis with the passage of the Clean Water Act of 1977 and the subsequent implementation of the Rural Clean Water Program. As part of this Laboratory's research on the occurrence, movement, transformation, fate, impact, and control of environmental contaminants, data and analytical methodologies are developed to assess the causes of and possible solutions to adverse environmental effects of irrigated agriculture.

This report details an effort to demonstrate that improved technology and management can reduce the salt load in irrigation return flows in the Mesilla Valley of New Mexico. The impact of canal lining, irrigation scheduling, and alternative water application methods was evaluated. An economic analysis of the benefits of implementing these practices valley-wide was also made. This report should benefit farmers, state action agencies, and environmental managers as they attempt to identify and implement pollution control strategies relevant to western irrigated agriculture.

Clinton W. Hall

Clinton W. Hall
Director
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PREFACE

This report presents data from studies conducted on a 450-acre Demonstration Farm and on a 4-acre test site to evaluate effects of irrigation management on return flow quality. The economic impact of applying salinity control programs to the Mesilla Valley in southern New Mexico is also investigated. Other reports have been prepared for the evaluation of a hydro-salinity computer model (Gelhar and McLin, 1979). The more detailed aspects of this multidisciplinary project can be found in New Mexico Water Resources Research Institute publications (Sammis, 1980; Wierenga, 1979; and Lansford et al., 1980).

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ABSTRACT

The general objective of this project was to demonstrate the effect of alternative water management practices on the quality of drainage return flow and soil salinity in the Mesilla Valley in southern New Mexico. The project area consisted of a 4-acre test site and a 450-acre demonstration site. The feasibility of irrigating at or near 100 percent irrigation efficiency with water of medium salinity (1200 ppm), while maintaining optimum crop yield over a period of many years, was demonstrated on the 4-acre test site at the New Mexico State University Plant Science Farm. At the 450-acre Demonstration Farm, a combination of present day irrigation technology was used to show how, through modern water management, return flow quality and quantity can be improved. In addition, an economic analysis was performed to determine the economic feasibility of the water management practices demonstrated.

Irrigation efficiency and irrigation interval had a significant effect on chloride concentration of saturation extracts of samples taken from the rooting depth of surface irrigated plots. In addition, there were significant increases in salt content of the soil irrigated for five years with a trickle system, but the trickle plots yielded six percent more lint cotton on 25 percent less water than did the surface irrigated plots with essentially no difference in lint quality.

The results of this study indicated that by using irrigation scheduling, farm irrigation efficiency can be increased by 13 to 23 percent. However, field irrigation efficiency was found to vary from 80 percent down to 35 percent regardless of type of crop or field size. Trickle-irrigation of a 1.3 hectare pecan orchard resulted in irrigation efficiencies near 100 percent with apparent above average yields.

Economic analysis of alternative water management systems for the Mesilla Valley indicated that irrigation scheduling service (ISS) reduced irrigation water use by 17 to 24 percent while net returns to land risk increased by 5 to 9 percent. A combination of ISS and sprinkler-irrigation of vegetable crops for seed germination resulted in the highest net returns to land and risk with only minor savings in irrigation water use. ISS and trickle irrigation management practices only added marginal water savings along ISS, but net returns would be reduced drastically.

ISS could reduce irrigation return flows to the Rio Grande from 30 to 36 percent and the salt load to the river by 38,000 to 42,000 tons annually. ISS plus sprinkler could reduce irrigation return flows by an additional 4 to 5 percent and the salt load by an additional 4,000 to 5,000 tons annually. ISS and trickle-irrigation could reduce return flows 7 to 16 percent below the ISS alternative and the salt load in the river by 9,000 to 23,000 tons annually.

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The following individuals contributed to various aspects of the work reported here:

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SECTION 1

INTRODUCTION

The quality of irrigation return flow represents a major problem in the western United States. The water of the Upper Rio Grande has been reported as a classic example of water quality degradation. Mineral pollution is the most serious problem in the Upper Rio Grande Basin. The problem is serious because the basin is approaching, or has approached, conditions of full development and utilization of the available water resources. There is a progressive increase in the concentration of total dissolved solids and the percent sodium from the upper to the lower sampling stations in the Upper Rio Grande Basin. The relatively large increase in dissolved solids in the river along the irrigated areas is, to a large extent, due to the concentrating effect of irrigation.

Almost all of the valley land in the Upper Rio Grande Basin has a high water table. Where irrigation exists, drainage canals divert water from the "near-surface aquifers" into the Rio Grande. In the Mesilla Valley, as in many other areas, high equilibrium salinity concentrations are known to exist in the near-surface aquifer. The key to achieving a reduction in salt loading is to lower the groundwater levels. The most effective means for lowering groundwater levels is to reduce the source of groundwater flows, which can be accomplished by reducing seepage losses through lining canals and laterals, or by reducing deep percolation losses resulting from excessive irrigation by improved on-farm water management practices.

The U. S. Senate Select Committee (1961) and a U. S. Water Resources Council Study (1968) reports estimated that the Upper Rio Grande and Pecos Basins were the shortest on water in relation to projected future demands of any basin in the continental United States. The Water Resources Council study identified the major problems as water deficiencies, groundwater storage depletion, and poor water quality because of mineral pollution. The past 15-year average inflow to Elephant Butte Reservoir is only about 65 to 70 percent of the long-term average inflow. Thus, a program for reduction of mineral pollution loading is urgently needed in order to protect existing water uses from mineral quality degradation during low-flow periods, and to prevent the serious restriction of future basin-wide economic development.

The general objective of this project was to demonstrate the effect of alternative water management practices on the improvement of the quality of drainage return flow and soil salinity in the Upper Rio Grande Basin. The project area consisted of a 4-acre site and a 450-acre demonstration site. The feasibility of irrigating at or near 100 percent irrigation efficiency

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with water of medium salinity (1200 ppm.), while maintaining optimum crop yields over a period of many years, was demonstrated on the 4-acre test site at the New Mexico State University Plant Science Farm. At the 450-acre demonstration site, a combination of present day irrigation technology was used to show how, through modern water management, the return flow quality and quantity can be improved. In addition, an economic analysis was performed to determine the economic feasibility of the water management practices demonstrated.

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SECTION 2

CONCLUSIONS

FIELD PLOT DEMONSTRATION

In 1976 and 1977 irrigation treatment (efficiency and irrigation interval) had a significant effect on the electrical conductivity (EC_e) and chloride concentration of saturation extracts of samples taken from the rooting depth in the surface-irrigation plots. EC_e and chloride concentrations were significantly higher for the plots irrigated near 100 percent efficiency. However, irrigation treatments did not have a significant effect on EC_e and chloride concentration of soil below 150 cm, indicating that improving irrigation efficiency has no immediate effect on the quality of percolation water.

Based on the chloride concentrations of the soil water percolating below the root zone in the surface-irrigated plots, leaching fractions of 0.14, 0.11 and 0.09 were obtained for the planned 80, 90 and 100 percent efficiency treatments, respectively.

Surface-irrigation treatments had no significant effect on cotton yield at the five percent level of probability during the years 1972 through 1977. However, yields tended to decrease with increased irrigation efficiency, except in the 50 percent depletion (two weeks irrigation interval) treatment. For the conditions of the experiment, less frequent irrigating with some leaching provides the highest cotton yields.

There was a significant increase in the salt content of soil irrigated for five years with a trickle system, especially in the 30 to 130 cm depth range. The salinity increase was 25 percent for the plots irrigated at 0.2 bar and 110 percent for the plots receiving 25 percent less water than the 0.2 bar treatment.

Salt contents were significantly higher in the soil between the trickle lines than below the trickle lines to a depth of 50 cm. Below 50 cm, there were no significant differences in salt content below or between the trickle lines.

Averaged over five years and all treatments, the trickle irrigated plots yielded six percent more lint cotton than the surface irrigated plots, with essentially no differences in lint quality. An average of 35 percent more water (irrigation and rain) were applied to the surface-irrigated plots than to the trickle-irrigated plots.

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There was a strong inverse correlation between flow of water in the Del Rio Drain and its quality. The average electrical conductivity of the water in the Del Rio Drain as measured from 1972 to 1978 was very close to the average electrical conductivity of the water from 1921 to 1936, indicating a near equilibrium of the valley along the Del Rio Drain.

DEMONSTRATION FARM

Using irrigation scheduling on the 450-acre Demonstration Farm, the yearly irrigation efficiency was 63 percent, a 13 to 23 percent increase over the 40 to 50 percent irrigation efficiency considered normal for the Mesilla Valley.

The results show that the overall irrigation efficiency of the Demonstration Farm (63 percent) was above average with irrigation scheduling, although large variations from field to field were noted ranging from 80 percent to 35 percent. Field irrigation efficiencies did not correlate with the type of crop being grown or field size.

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The canals at the measurement sites had very low seepage losses. In the main canal, the maximum loss per 1000 meters of canal ranged from 3 percent down to0.2 percent, depending upon the flow in the canal. Seepage losses from the farm ditches measured were 1.1 to 5.6 percent of the total applied water over the growing season.

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Trickle-irrigation of the pecan orchard resulted in irrigation efficiencies of nearly 100 percent. Additional measurements are necessary to determine if any detrimental effects would occur from salt accumulation due to the continued use of trickle-irrigation with efficiencies approaching 100 percent.

There was a negative correlation between groundwater height on the Demonstration Farm and increase in drain flow through the farm during 1977. During 1975 and 1976, drain flow measurements at two locations did not show a statistical increase or decrease in the flow through the Demonstration Farm. Consequently, changes in drain flow did not correlate to changes in groundwater height. Short-term changes in flow rates during the growing season may be influenced more by the amount of excess surface water being returned into the drains than by the height of the groundwater table.

The effect of irrigation scheduling on drain flow quantity was not detectable. However, irrigation scheduling at the Demonstration Farm was estimated to increase the irrigation efficiency by approximately 13 percent.

Salinity of the drain water showed a negative correlation with flow, decreasing as drain flow increased in all years. Groundwater quality at the sampling points on the Demonstration Farm indicated an increase in nitrate content and a decrease in total salinity with depth below the water table.

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ECONOMIC ANALYSIS

For the three water supply periods (1967, 1973, and 1976) significant quantities of groundwater could be saved (17 to 24 percent) while the returns to land and risk could be increased by 4.8 to 9.2 percent by the incorporation of irrigation scheduling service (ISS). Irrigation return flows could be reduced by 30 to 36 percent and the salt load on the Rio Grande reduced 38,000 to 42,000 tons with the implementation of ISS.

The combination of ISS and sprinkler-irrigation for vegetable crop seed germination could add an additional reduction of two to three percent in irrigation water savings. But net returns to irrigated agriculture would be expected to decrease below that expected for ISS in two of the three water supply periods by 1.4 to 3.1 percent and only increase by about 0.4 percent in above average surface water supply period. Irrigation return flows would decrease by an additional four to five percent and the salt load on the Rio Grande only be reduced by 4,000 to 5,000 tons annually.

The combination of ISS and trickle-irrigation for orchards could significantly reduce surface water use (6 to 15 percent) with increases in groundwater (0.4 to 9 percent) above the ISS alternative. However, significant decreases in net returns would be encountered. Irrigation return flows would decrease by 7 to 16 percent below the ISS alternative which translates to 9,000 to 23,000 tons of salt to the Rio Grande annually.

A combination of ISS, sprinkler- and trickle-irrigation management practices would reduce surface supplied irrigation water use by 6 to 16 percent and groundwater use by 16 to 18 percent below that of current irrigation practices. The impact on net returns would vary from a reduction of nine percent to an increase of about one percent annually. The reduction in irrigation return flows could be 40 to 50 percent and the salt load on the Rio Grande reduced 50,000 to 70,000 tons annually.

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SECTION 3

RECOMMENDATIONS

1. For maximum benefit of water supplies in the Mesilla Valley, farm irrigation systems should be designed for minimum leaching.

2. Increased efforts are needed to better define the actual water use of crops in the Mesilla Valley, in particular of pecan orchards.

3. Trickle-irrigation, though not economical at present, may be used to maintain or improve yields of cotton with 25 percent less water. Demonstration projects on the use of trickle-irrigation for vegetable production in the Mesilla Valley are recommended. Trickle systems economically may be justified for quality and marketing considerations.

4. Increased efforts are needed to further encourage the utilization of irrigation scheduling service and sprinkler-irrigation of vegetable crops for seed germination in the Mesilla Valley.

5. Use of a combination of irrigation systems should be investigated for seed germination, i.e. trickle or sprinkler and flood.

6. Equipment to measure applied water to each field should be incorporated in farm irrigation systems to improve field irrigation efficiencies.

7. Continued monitoring of the salinity in the soil beneath the field sites where irrigation scheduling is practiced would help to determine the long-range effect of increased efficiency on salinity buildup.

8. Future studies should be directed toward predicting the long term effects on the salt load in the Rio Grande resulting from improvements in irrigation efficiency in the irrigated areas along the Rio Grande in New Mexico, and taking into account continued use of groundwater as well as increased urban and industrial developments.

9. A detailed study of the hydrology of the Mesilla Valley should be undertaken to determine the effect of mixing on the quality of the groundwater.

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SECTION 4

PHYSICAL DESCRIPTION OF THE MESILLA VALLEY

The Mesilla Valley is located in Dona Ana County in southern New Mexico. It extends from Selden Canyon north of Radium Springs, New Mexico, southeasterly to the New Mexico-Texas border. The Rio Grande enters the Mesilla Valley at the junction of Selden Canyon and flows southeast past Las Cruces and Anthony to El Paso Canyon. The Valley is approximately 96 kilometers long and about 10 kilometers wide at the widest point just south of Las Cruces (Figure 1).

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The irrigated cropland is located predominantly in the valley floor along the Rio Grande. A small amount of the cropland is located on the mesa on either side of the valley. The major flood plains of the valley converge in the vicinity of Las Cruces and drain into the Rio Grande.

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TOPOGRAPHY

The Mesilla Valley is bounded from north to south on the east side by the San Andres, Organ, and Franklin Mountain ranges and on the west side by mesa highlands. The valley has a relatively smooth alluvial floor and is bordered by steep bluffs about 15 to 30 meters high, composed of loosely cemented sand, silt, clay, and gravel. From the bluffs, sloping plains extend away from the river to the mountains.

The drainage into the valley is primarily from arroyos in the mesa highlands toward the river. Drainage is from northwest to southeast. The valley floor varies in altitude from about 1,250 meters at Seldon Canyon to 1,130 meters in El Paso Canyon. This elevation change represents a gradient of approximately 0.13 percent.

The Mesilla Valley has a recent valley fill less than 45 meters thick, underlain by the Santa Fe Formation, a mixture of sand and gravel interspersed by numerous clay layers. The valley fill is a relatively fast backfill of an earlier river cut. The backfill and valley floor were completed about 10,000 years ago. The upper fill is fine grain sands and silts, while the lower part of the fill is mainly gravel. All groundwater within the Mesilla Valley is within the valley fill.

CLIMATE

The Mesilla Valley climate is semi-arid. It is characterized by low

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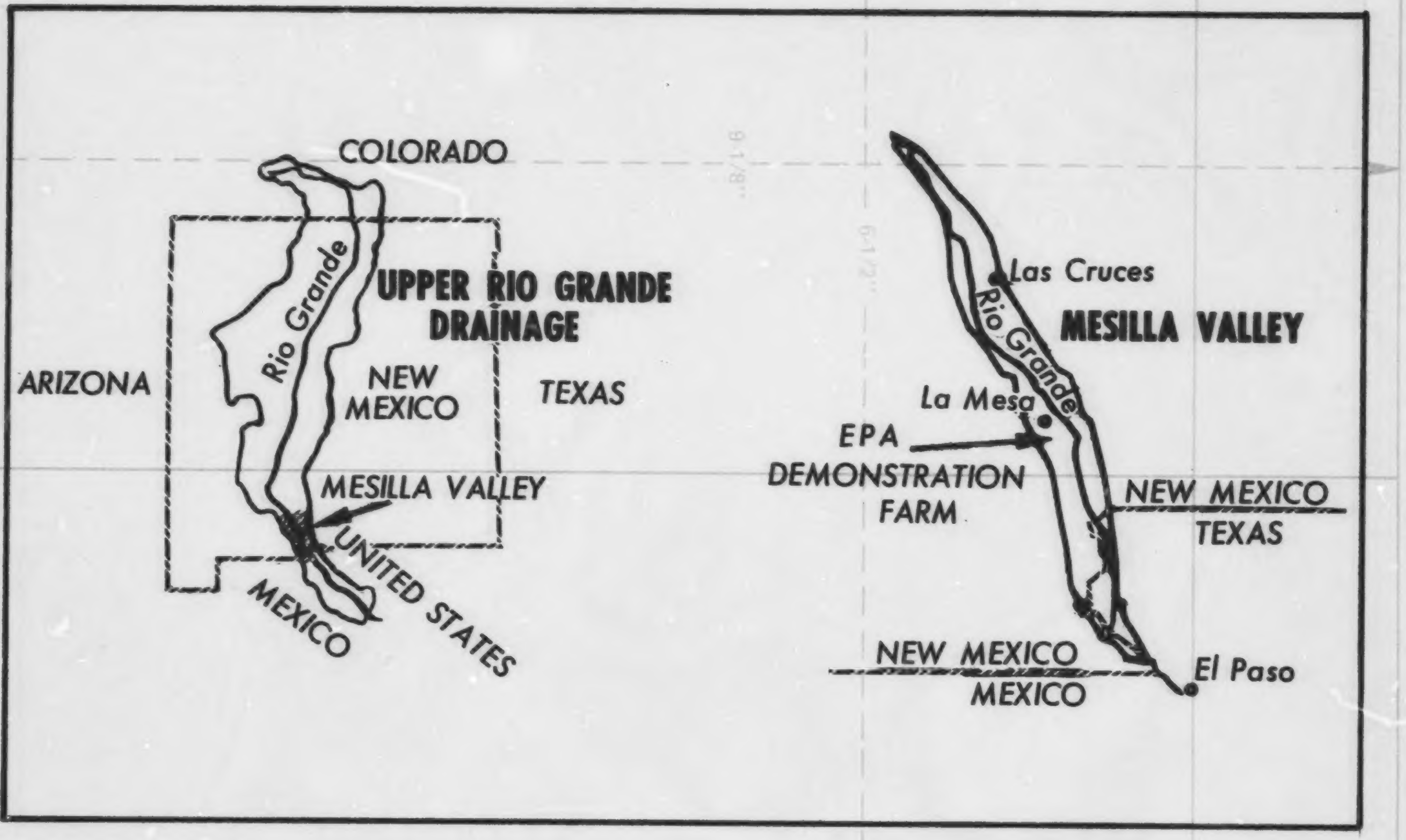
COLORADO
UPPER RIO GRANDE DRAINAGE
Rio Grande
ARIZONA
NEW MEXICO
TEXAS
MESILLA VALLEY
UNITED STATES
MEXICO
Las Cruces
MESILLA VALLEY
Rio Grande
La Mesa
EPA DEMONSTRATION FARM
NEW MEXICO
TEXAS
NEW MEXICO
MEXICO
El Paso

Figure 1. Location of the Mesilla Valley within the Upper Rio Grande Drainage Basin

annual precipitation, low humidity, high temperature, and persistent wind movements, particularly in the spring. The summer months are, in general, the wettest ones when tropical air masses from the Gulf of Mexico predominate the area and cause thundershowers. These thundershowers are occasionally accompanied by hail which may cause severe crop damage. The high temperatures and low relative humidity result in rainfall being evaporated or transpired rapidly.

The mean annual temperature in the valley is about 15 degrees Centigrade. The winters are usually mild and dry, and temperatures above 38° Centigrade are not uncommon in the summer months. The frost-free season in the valley usually begins in mid-April and lasts about 200 days until late October.

SOILS

The soils of the Mesilla Valley fall into two distinct divisions--the alluvial section, or the Rio Grande Valley fill, and the narrow margin of upland area of the piedmont slopes. Most of the soil material in the valley floor is alluvial deposit laid down by the Rio Grande. A large portion of this fill has been transported great distances. With no perennial streams and numerous drainage ways, little material from the valley slopes is transported to the valley floor in any one year.

The soils of the Rio Grande flood plain in the Mesilla Valley are of the Glendale-Harkey-Brazito association (USDA, SCS; 1977). These soils are brownish-gray to pale brown and are underlain by alluvial sediments ranging in texture from coarse sandy loam to stratified loams. The principal soil classes are Glendale clay loam, Harkey loam, and the Anthony-Vinton loam, (Table 1). Harkey brown loam and Anthony-Vinton loam are characterized as slight to moderately stratified, with thin layers of heavy-textured materials in the subsoil. These soils have very slow to rapid moisture penetration rates and some accumulations of alkali. They occupy the nearly level to gently sloping areas throughout the Mesilla Valley. The Glendale clay loam soils are the most extensive of this association in the valley, occurring in large areas along the river channel in the northern part of the valley and in narrow belts in the southern portion of the valley.

The soils of the highland areas above the valley floor are of the Bluepoint-Calizo-Yturbide associations. The surface layer is generally sandy loam to gravelly loam underlain by sand and gravelly sandy loam. The principal soil type occurring in these areas is the Bluepoint loamy sand (Maker, et al., 1971). This soil forms a belt along the slopes adjacent to the valley floor. It is characterized by very rapid permeability, low fertility, and low waterholding capacity.

WATER CONVEYANCE SYSTEM

The irrigation water conveyance system of the Mesilla Valley consists of an intricate network of primary canals branching into numerous primary and secondary laterals (Figures 2a and 2b). The primary canals are the Leasburg canal which originates at the Leasburg dam and the East and West Side canals which originate at the Mesilla dam. The Leasburg canal branches into three

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TABLE 1. SOILS OF THE MESILLA VALLEY, NEW MEXICO

Soil Class	Estimated Acres* in Soil Survey (hectares)	Estimated Percent in Mesilla Valley (percent)
Agua loam	3,367	6.87
Agua clay loam	264	0.54
Agua variant soils, moderately wet	251	0.51
Agua variant and Belen variant soils	754	1.54
Anapra silt loam	243	0.51
Anapra clay loam	2,886	5.89
Anthony-Vinton fine sandy loam	2,342	4.78
Anthony-Vinton loam	2,717	5.55
Anthony-Vinton clay loam	833	1.70
Armijo loam	81	0.16
Armijo clay loam	1,443	2.94
Armijo clay	1,371	2.80
Belen loam	86	0.18
Belen clay loam	963	1.96
Belen clay	3,379	6.90
Belen variant soils	150	0.30
Brazito loamy fine sand	2,720	5.55
Brazito very fine sandy loam, thick surface	2,702	5.52
Glendale loam	3,165	6.46
Glendale clay loam	8,092	16.52
Glendale clay loam, alkali	241	0.49
Harkey fine sandy loam	237	0.48
Harkey loam	7,564	15.44
Harkey loam, saline and alkali	120	0.24
Harkey clay loam	3,020	6.16

*Acreages include Rincon Valley (1,738 hectares) portion of Elephant Butte Irrigation District.

Source: U.S.D.A., Soil Conservation Service, "Soil Survey of Dona Ana County, New Mexico", Advance copy, April 1977.

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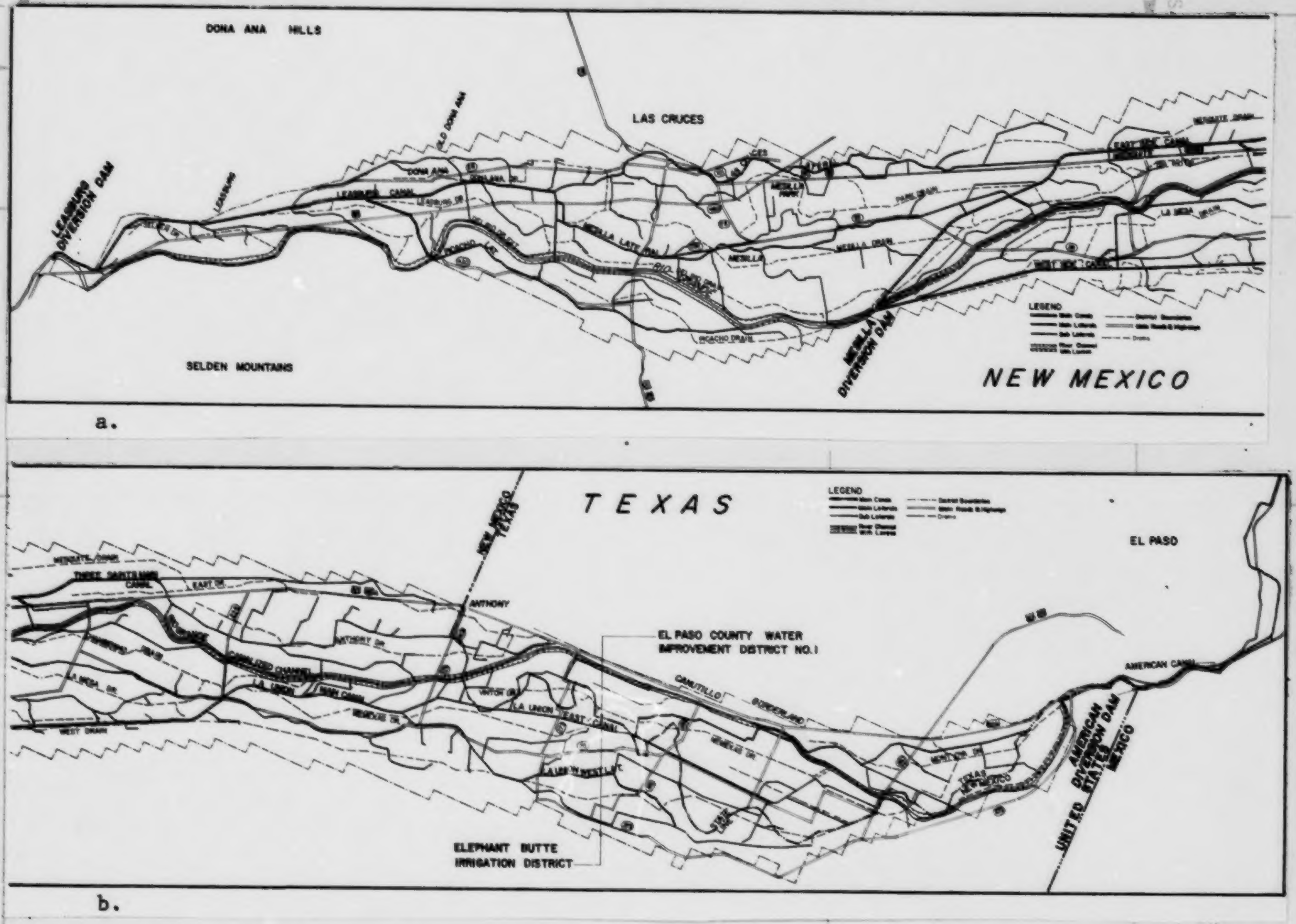
DONA ANA HILLS
LAS CRUCES
SELDEN MOUNTAINS
LEASBURG DIVERSION DAM
LEASBURG CANAL
DONA ANA
MESILLA
MESILLA LATERAL
MESILLA DRAIN
PICACHO DRAIN
RIO GRANDE
LA MESA DRAIN
WEST SIDE CANAL
EAST SIDE CANAL
MESILLA DIVERSION DAM
LEGEND
Main Canals
Main Laterals
Sub Laterals
River Channel With Levees
District Boundaries
Main Roads & Highways
Drains
NEW MEXICO
a.
TEXAS
NEW MEXICO
TEXAS
ANTHONY
EL PASO COUNTY WATER IMPROVEMENT DISTRICT NO.1
ELEPHANT BUTTE IRRIGATION DISTRICT
CANUTILLO
BORDERLAND
LA UNION EAST CANAL
LA UNION WEST LAT.
WEST DRAIN
EAST DR.
ANTHONY DR.
LA MESA DR.
EL PASO
AMERICAN CANAL
AMERICAN DIVERSION DAM
UNITED STATES
MEXICO
b.

Figure 2. Irrigation conveyance system for the Mesilla Valley.

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primary laterals--the Picacho which crosses the river to serve the west side between Leasburg and Mesilla dam before emptying in the river channel, and the Las Cruces and Mesilla laterals that branch into numerous secondary laterals to serve the east side before either emptying into the river channel or the East Side canal.

The East Side canal branches into two primary laterals which empty into the river channel below Anthony, New Mexico-Texas. The primary laterals of the East Side canal are the Anthony and the Three Saints laterals which branch into numerous secondary laterals to serve the lands on the east side of the river channel between the Mesilla dam and La Tuna Detention Farm. The West Side canal branches into two primary laterals, the La Union East and the La Union West. These three, the main canal and the two primary laterals, break into numerous secondary canals supplying the area on the west side of the river between Mesilla dam and El Paso dam with surface-irrigation water. A portion of the La Union East lateral crosses the river channel at Borderland to serve lands on the east side of the river.

A portion of the water released is diverted to the Rincon Division at Percha dam with the remainder flowing down the river channel through the Rincon Valley to be diverted later in the Mesilla and El Paso Divisions. A portion of the water diverted for the Rincon and Mesilla Divisions is returned by drains and wasteways to continue its flow into the El Paso Division of the Rio Grande Project.

Surface water for the Mesilla Division is diverted by the Leasburg dam into the Leasburg canal, and by the Mesilla dam into the East and West Side canals. The Leasburg dam is located at the head of the Mesilla Valley, and the Mesilla dam (Figure 2a) is located southwest of Las Cruces. Portions of the surface waters diverted for the Rincon Division that are returned to the river channel by drains and wasteways are diverted again at Leasburg dam. Also, portions of surface waters diverted at the Leasburg dam that are returned to the river are diverted again at the Mesilla dam. In addition, water diverted at Leasburg dam may be added to the East Side canal diversions from the Mesilla dam (Figures 2a and 2b).

DRAINAGE SYSTEM

The drains of the Mesilla Valley are a maze of intricately woven open ditches designed to carry excess groundwater away from the cropland into the river channel. The drains are also presented in Figures 2a and 2b. These drains are the primary subjects of studies to reduce irrigation return flows.

SURFACE WATER SOURCES

Irrigation water in the Mesilla Valley comes from surface and groundwater sources. The surface water is supplied by the Elephant Butte Irrigation District (EBID) through the facilities of Elephant Butte and Caballo Reservoirs with supplementary supplies being provided by district-owned wells. Groundwater is supplied by individual wells and is used as a supplemental source in most cases, except for lands located outside of the district boundaries where it is the only source of irrigation water. Pumpage is the

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primary source of irrigation water for approximately 1,940 hectares.

Surface Water Quantity

The quantity of surface water has not been a major limitation to irrigated agriculture in the Mesilla Valley since the drought in 1954-56. There have been three other years of shortages in 1964, 1972 and 1978.

The quantity of surface water released to project lands varies widely from year to year, depending upon the amount of storage in Elephant Butte and Caballo Reservoirs. Beginning in 1938, water released for irrigation of Rio Grande Project lands originated from Caballo Reservoir. Prior to 1938, surface waters for irrigation were released from Elephant Butte Reservoir.

The annual diversions and average diversions at the two dams in the Mesilla Valley are reported in Table 2 for the period 1938-1976, as well as the average total diversions for this period. The average total diversions from both dams for the 38-year period was 46,022 hectare-meters. The minimum diversion was 17,247 hectare-meters in the middle of the drought of 1954-56. The maximum diversion was in 1945 with 67,586 hectare-meters.

The diversions were the gross annual diversions in the Mesilla Unit of the Rio Grande Project, a portion of which was returned to the river by way of drains and wasteways to be diverted again. Therefore, a portion of the diversion at the Mesilla dam includes a portion of the diversion from Leasburg dam. Approximately 45 percent of the gross annual diversions of water by the three diversion dams in the Mesilla Valley were delivered to farms in the valley. The balance was El Paso Valley carriage, canal wastage, seepage, and other unaccounted for losses.

Monthly surface water deliveries to lands in the Mesilla Division of the Elephant Butte Irrigation District are presented in Table 3. These deliveries were calculated from information from the Bureau of Reclamation (1960-1975) and were the net deliveries to the farm (El Paso carriage, canal wastage, seepage, and other unaccounted for losses have been deducted). The average annual delivery to farms was 19,169 hectare-meters. Based on the 1976 acreage, the Mesilla Division of the Elephant Butte Irrigation District averaged about 0.59 hectare-meters per cropped hectare.

Surface water, however, does not represent the full supply of water necessary for the irrigation requirements of the crops produced in the Mesilla Division. Although the surface water is generally of better quality, it is necessary to pump some groundwater to meet the irrigation requirements. The groundwater pumpage will be discussed later in the section dealing with groundwater quantity and quality.

Surface Water Quality

Records of chemical analysis of the river at El Paso in 1966 and 1967 (USGS, 1974) indicated that the quality of the surface water varied generally with the quantity of water flowing in the river, becoming of poorer quality with small flows and better with larger flows. During the February to October

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TABLE 2. GROSS ANNUAL DIVERSIONS OF IRRIGATION WATER FROM THE RIO GRANDE IN THE MESILLA VALLEY, FOR THE PERIOD 1938 THROUGH 1976

Year	Leasburg Canal*	Mesilla Dam East Side Canal**	Mesilla Dam West Side Canal†	Total
	(hectare-meters)			
1938	18,621	9,730	24,994	53,345
1939	20,329	11,180	27,437	58,946
1940	19,093	10,039	24,630	53,762
1941	17,161	9,016	22,506	48,683
1942	23,738	11,725	29,314	64,777
1943	27,129	11,201	27,920	66,250
1944	25,205	10,903	26,526	62,634
1945	26,907	12,075	28,604	67,586
1946	25,373	10,700	26,039	62,112
1947	23,767	9,711	24,683	58,161
1948	22,671	10,284	24,902	57,857
1949	23,278	10,909	25,311	59,498
1950	23,931	10,239	24,209	58,379
1951	12,378	6,273	15,600	34,251
1952	12,451	6,938	16,367	35,756
1953	12,417	6,858	17,218	36,493
1954	6,230	4,612	11,103	21,945
1955	4,378	2,905	9,964	17,247
1956	4,359	3,454	10,395	18,208
1957	15,030	4,374	15,300	34,704
1958	20,100	8,608	22,148	50,856
1959	20,038	9,403	20,418	49,859
1960	19,214	9,577	21,400	50,191
1961	15,415	8,217	19,869	43,501
1962	18,251	9,550	21,154	48,955
1963	16,845	8,358	19,789	44,992
1964	9,645	2,373	10,010	22,028
1965	9,854	5,268	13,479	28,601
1966	15,313	7,002	17,386	39,701
1967	15,160	7,288	16,363	38,811
1968	18,467	8,439	20,497	47,403
1969	20,871	8,838	24,936	54,645
1970	20,309	8,888	23,450	52,647
1971	16,258	7,225	19,071	42,554
1972	10,690	4,359	11,516	26,565
1973	15,004	8,223	21,755	44,982
1974	17,603	8,841	23,365	49,809
1975	11,172	8,600	22,733	42,505
1976	18,033	10,219	25,640	53,892
Average	17,248	8,267	20,718	46,233

* Diversion at Leasburg dam to the east side of Rio Grande.
** Diversion at Mesilla dam to the east side of Rio Grande.
† Diversion at Mesilla dam to the west side of Rio Grande.

Source: United States Department of the Interior, Bureau of Reclamation, El Paso Office, unpublished data sheets, 1938-1977.

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TABLE 3. MONTHLY DELIVERIES* OF SURFACE WATER TO THE LANDS IN THE MESILLA DIVISION, ELEPHANT BUTTE IRRIGATION DISTRICT, NEW MEXICO, 1960-1976

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total
	Month												
	(hectare-meters)												
1960	5	2	3,201	3,316	2,017	3,452	3,617	5,343	3,864	106	28	10	24,960
1961	-	9	1,213	3,177	1,469	2,485	3,926	3,970	2,621	155	33	-	19,956
1962	5	9	2,855	4,239	1,781	4,399	5,139	5,219	2,692	94	14	-	26,454
1963	10	-	3,729	3,231	1,178	2,246	3,910	3,557	1,852	25	16	7	19,761
1964	5	-	280	862	21	284	530	760	956	.62	-	6	3,698
1965	-	-	4	1,069	10	2,031	4,105	4,456	3,089	118	-	-	14,485
1966	-	-	1,324	3,848	1,719	2,312	3,238	4,261	2,778	152	24	3	19,655
1967	5	-	4,110	1,040	719	958	2,062	2,519	2,475	100	37	-	14,024
1968	11	12	2,671	1,642	918	2,342	2,723	3,884	2,121	106	29	-	16,464
1969	-	-	4,161	1,912	1,390	3,485	4,548	6,104	1,739	134	32	-	23,506
1970	-	-	4,014	2,745	2,464	3,230	5,287	4,916	2,981	130	25	-	25,792
1971	-	-	3,365	1,397	909	1,701	2,936	3,147	1,383	24	-	-	14,861
1972	-	-	2,488	852	228	218	1,608	1,437	392	5	-	-	7,228
1973	-	-	2,305	2,601	1,896	3,099	3,730	5,138	3,947	189	-	-	22,904
1974	-	-	4,028	2,986	2,570	4,070	3,459	3,966	2,482	12	-	-	23,572
1975	-	84	2,669	2,701	2,610	3,265	4,443	4,353	2,488	461	-	-	23,074
1976	498	983	3,297	3,338	3,366	3,172	3,562	4,384	2,374	108	-	-	25,048
Average	-	5	2,714	2,358	1,362	2,483	3,455	3,935	2,370	109	1	-	19,169

* Amount of water delivered to the farm headgates excludes: canal wastage, seepage, and other unaccounted for losses (calculated from monthly per acre deliveries and annual irrigated acreage).

Source: United States Department of the Interior, Bureau of Reclamation, El Paso Office, unpublished data sheets, 1960-77, 10 pp.

period 1974, the quality of the river averaged about 920 mmhos/cm^2 of specific conductance and the river flow averaged 570 m^3/sec. During the April to September period 1975, the quality of the river flow averaged 875 mmhos/cm^2 of specific conductance and the river flow averaged 670 m^3/sec.

In 1974, the U. S. Geological Survey reported in Water Resources Data for New Mexico that chemical quality of water in the Rio Grande increased in dissolved solids content by nearly 41 percent between Leasburg, New Mexico, and El Paso, Texas. The surface water of the Rio Grande increased in concentration of dissolved solids downstream from Caballo dam to El Paso, with the major increases being in silica, calcium, sodium, sulfate, chloride, and boron. Records of the chemical quality of the surface water diverted at the Mesilla dam were not available, but the surface water is assumed to be lower in quality than when it passed the Leasburg dam and higher in quality than at El Paso.

The quality of surface water in the Mesilla Valley is not considered a limitation for crop production except in the southern portion below Anthony, New Mexico. In this area, the problem of lower quality surface water is compounded by the existence of poor quality groundwater.

GROUNDWATER SOURCES

Groundwater in the Mesilla Valley is used 1) to supplement surface water for agricultural use; 2) for municipal use in Las Cruces, Anthony, and numerous small villages; 3) for industry, and 4) for rural domestic use.

There are about 1,940 cultivated hectares in the Mesilla Valley dependent entirely on groundwater for irrigation, and about 87 percent of the approximately 32,382 cultivated hectares within the Elephant Butte Irrigation District in 1976 used groundwater as a supplemental source. The irrigation wells in the valley vary in depth, but most are from 12 to 22 meters in depth and water quality is poor in comparison to the sufface water. Recently, some large wells have been completed down to 100 m. or more. The depth of irrigation wells is greatly affected by the depth of the water table in the valley. The amount of water in storage in the valley fill and the amount of pumpage is not well known. The pumpage varies from year to year inversely with usable precipitation and the supply of surface water.

Groundwater Quantity

The primary groundwater sources are water seepage from the river, canals, laterals, and irrigation water applied to the lands, precipitation, runoff from arroyos from the mesas to the valley, and groundwater flow from the mesa lands bordering the valley.

Groundwater Quality

The groundwater quality in the Mesilla Valley varies by location. The quality generally decreases with distance down the valley (Gelhar and McLin, 1979). The greatest concentrations in TDS are in the southern portion of the valley. The quality of water is usually better with increased depth. Fresh

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water exists within the Santa Fe group sub-stratum below ground level to a depth of about 365 meters extending from near the northern end of the Mesilla Valley generally south to Canutillo (King et al., 1969). The Santa Fe group generally has water quality with electrical conductivity of about .57 x 10^3 mmhos/cm. South of Canutillo, the water from the Santa Fe group increases in mineral content until it becomes unfit for most uses. This increase in mineral content of the water in the Santa Fe group from north to south in the valley is thought to be due to incomplete flushing of ancient playa lake sediments and to the increased mineral concentrations of the groudwater in the upper horizons by evapotranspiration (Leggat et al., 1964).

Most of the groundwater used for irrigation in the Mesilla Valley is shallow groundwater. This water is of relatively good quality (less than 3000 ppm TDS) throughout most of the valley but contains more dissolved solids than the water in the underlying Santa Fe group. South of Canutillo, the shallow wells, while having a high concentration of dissolved solids, are of better quality than the water of the Santa Fe group. Leggat, et al., (1964) reported that increases in groundwater withdrawals in the Mesilla Valley were likely to result in increases in the dissolved solids content of the groundwater. Thus, if the shallow aquifer is to remain a source of supplemental supply for irrigation, withdrawals of water must not be so great that an unfavorable salt balance results. Groundwater quality is considered a moderate limitation to about one-third of the irrigated cropland in the valley, and a severe limitation to about one-sixth, primarily in the southern portion of the valley. The deterioration in the quality of shallow groundwater and groundwater in the Santa Fe group is regarded as a major limitation to the further development of shallow groundwater sources for irrigated cropland in the lower portion of the Mesilla Valley.

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SECTION 5

FIELD PLOT DEMONSTRATION

INTRODUCTION

Field plot studies were conducted at the Plant Science Research Center at Las Cruces, located along the east bank of the Rio Grande River, eight miles southwest of the New Mexico State University campus. The Center consists of 82 hectares of irrigated farmland. Research projects on the farm range from plant breeding and soil-water management to weed control. Crops being investigated include: cotton, alfalfa, pecans, chile peppers, turf grass, crambe and others. An underground irrigation system provides for water transport, both surface and groundwater, to individual fields.

In 1971 a detailed field plot experiment was initiated on a 0.81 hectare (2-acre) site at this farm (Wierenga, 1977). A 20 cm (8 inch) irrigation well was constructed to provide water of relatively constant quality for the field plot experiment. The field plot experiment reported here was conducted at this same site. The objectives of this experiment were:

1. To determine over a period of years the changes in soil salinity and crop yields in well-controlled field plots irrigated at or near 100 percent irrigation efficiency, and
2. To determine the feasibility of storing salts below the root zone by irrigation at high field water application efficiencies.

MATERIALS AND METHODS

Field Facilities

The soil at the Plant Science Research Center was heterogeneous, which is characteristic of alluvial soils in the Mesilla Valley. The soil profile consisted of about 30 cm silty clay loam over 20 to 30 cm of clay, over a variable amount of silty loam. The latter changed rather abruptly into a medium sand. The depth to the sand on the two acre site varied between 60 to 120 cm below the soil surface. Root penetration into the medium to fine sandy subsoil appeared to be almost negligible. Data on the physical properties of the soil at the site are reported in Wierenga (1977).

The field plot layout at the experimental site was modified from the layout used during the previous study. The plastic and wood borders

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installed in the fall of 1971 had deteriorated, and needed to be rebuilt. Furthermore, it had been very difficult to till the soil and prepare a seedbed within the plastic borders of the 8 x 8 meter plots. As it had been impossible to construct furrows within the borders, the area within each plot had to be irrigated by surface flooding. Flooding caused compacting of the surface soil resulting in the development of a surface crust which impeded emergence and stand development.

In the modified design, standard furrows with 1 m row spacings were made in the north to south direction. The uncultivated area adjacent to the old plots was also prepared for planting, so that the size of each "new" plot became nearly double the size of each "old" plot. Figure 3 shows that each new plot lies over two old plots, and that one plot number per replication was deleted (e.g., numbers 10, 20, and 30). Table 4 lists new plot numbers and treatments with the list of old plot numbers and treatments. For the purpose of data analysis one half of the "new" plots, those overlying "old" plots, were called "A" plots, while the other half on the previously uncultivated area were called "B" plots.

The trickle plots also represented in Figure 3, were maintained at the same location for the duration of the experiment. However, the trickle lines with Drip-Eze emitters, which had been used during the early part of the experiment, were replaced with Bi-Wall tubing having orifices spaced at 30 cm intervals (Reed Irrigation Systems, El Cajon, California). The Bi-Wall tubing was installed 5 cm below the surface of the soil.

Irrigation water for the experiment was from the 20 cm irrigation well adjacent to the field plot area. The quality of the water was monitored by taking water samples at regular time intervals, and analyzing the samples in the laboratory.

The observation wells, installed during the previous study to monitor quality changes in the underlying aquifer and to monitor the water quality versus depth relationship within the shallow aquifer, were sampled throughout the study.

During the previous study two water monitoring stations had been constructed along the Del Rio Drain. The Del Rio Drain runs approximately parallel to the Rio Grande for a distance of about 32 km, and drains a large portion of the Mesilla Valley. It is one of the eight major drains in the valley having continuous flow throughout the year. The drain borders the experimental site to the east. One station, station B, was located adjacent to the plot area, and the second station, station A, was situated 4.5 km upstream. Water samples were taken at the two stations at weekly intervals. The discharge at each of the two locations was determined with a current meter once a week.

Weather data were collected at a weather station west of the experimental site. The following measurements were made: incoming solar radiation, wind velocity, air temperature, relative humidity, rainfall, pan evaporation, and maximum and minimum temperature. The weather station and the instruments used for making the measurements are described in Wierenga (1977).

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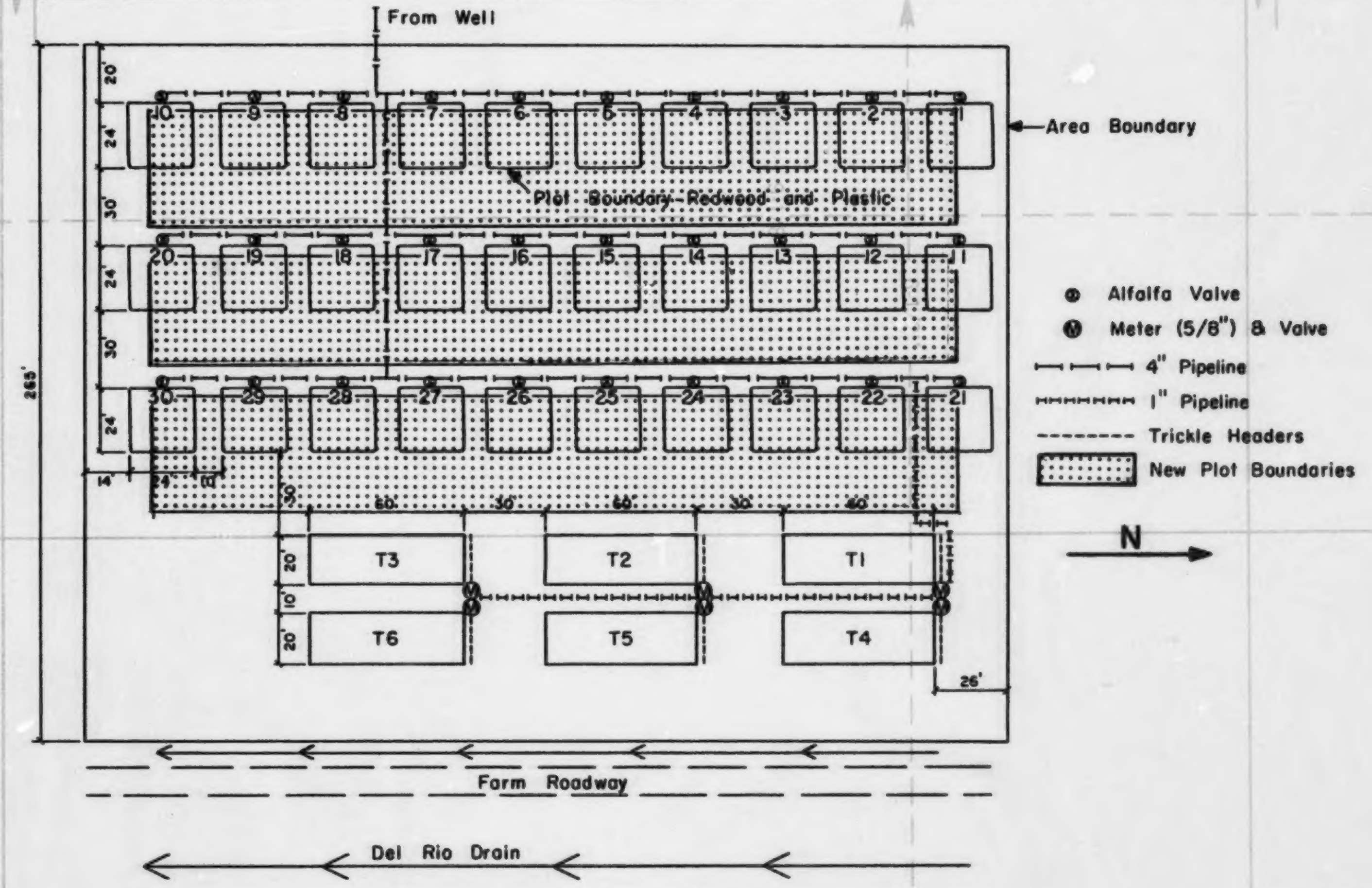
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Alfalfa Valve
Meter (5/8") & Valve
4" Pipeline
1" Pipeline
Trickle Headers
New Plot Boundaries
N
Farm Roadway
Del Rio Drain

Figure 3. Layout of experimental site with the numbering system for new and old plots

EXPERIMENTAL DESIGN AND FIELD PLOT MEASUREMENTS

The main treatment effects applied to the surface-irrigated plots were frequency of irrigation and rate of water application. During the previous study, frequency of irrigation was determined on the basis of the amount of "available" water in the soil profile. During the present study, irrigation frequency was arbitrarily set at intervals of 1 week, 2 weeks, or 3 weeks, respectively (Table 4).

TABLE 4. FORMER AND NEW IRRIGATION TREATMENTS AT THE EXPERIMENTAL SITE

Trmt. Number	Former Plot Numbers	Former Treatments: Depletion (percent)	Former Treatments: Efficiency (percent)	New Plot Numbers	Present Treatments: Irrigation Interval (days)	Present Treatments: Depth of Irrigation Water (cm)
1	2,14,29	25	80	2,14,28	7	71.1
2	5,20,25	50	80	4,19,25	14	71.1
3	6,16,21	75	80	5,16,21	21	71.1
4	10,18,24	25	90	9,18,24	7	61.0
5	1,15,30	50	90	1,15,29	14	61.0
6	3,11,23	75	90	3,11,23	21	61.0
7	9,12,26	25	100	8,12,26	7	50.8
8	8,17,27	50	100	7,17,27	14	50.8
9	7,13,22	75	100	6,13,22	21	50.8

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These latter frequencies differed from those used before, especially during the early part of the growing season. However, during the main part of the growing season differences between frequency treatments were relatively small. From a project management point of view it was more convenient to irrigate at regular, predetermined time intervals.

The rates of water application to the surface-irrigated plots were also changed for the present study. Application rates of 51, 61 and 71 cm of water, including rainfall, were chosen for the last two years of the experiment. From previous experience, it was found that cotton plots receiving a total of 51 cm of water, have essentially no leaching losses and approximated 100 percent irrigation efficiency. The use of predetermined amounts of

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irrigation water was more convenient from an experimental point of view than the use of variable rates which had to be determined for each irrigation. The irrigations were scaled to an estimated evapotranspiration curve so that the heavy irrigations coincided with the peak evapotranspiration rates.

During the first year of the experiment a Mexican drawf spring wheat (variety Cajame 71) was seeded. Following the harvest of the wheat the plots were rebuilt and, during the summer, fallowed. Winter barley was planted in the fall of 1975 and harvested in April 1976. No yield data were taken because of plant damage from aphids. The barley was primarily planted to control soil-born diseases. Variety 1517-75 cotton was planted on May 7, 1976 and variety 52-44 cotton was planted on April 23, 1977, in both the area overlying the "old" plots, and on the previously uncultivated area adjacent to it. All plots were machine harvested. Yield data for the cotton were obtained by harvesting four rows in each plot. Cotton sub-samples were taken from each plot for quality analysis by the New Mexico State University Cotton Quality Analysis Laboratory.

As soon after harvest as possible, soil samples were taken inside each plot at 20 cm depth increments to a final depth of 160 cm below the soil surface. The samples were air dried and saturation extracts prepared. The electrical conductivities of the saturation extracts were determined. The chloride concentrations of the fall '76 and fall '77 saturation extracts were also determined. In the previous experiment soil samples had been taken at two locations within each plot and composited. During the last two years of the present experiment, soil samples were taken at three locations within each plot and analyzed separately. Two of the three locations in each plot were over the "old" plots, while the third location was within the previously uncultivated area (Figure 3).

In 1976, soil solution samples were withdrawn with 5-cm O.D. soil solution samplers. The samplers were placed with their tips 30 cm below the clay-loam overlying the sand in each plot. The samples were collected throughout the growing season and analyzed for chloride concentration only.

LABORATORY PROCEDURES

The procedures used for chemical analysis were the same as those formerly used (Wierenga, 1977) and are described in "Methods for Chemical Analysis of Water and Wastes" (Environmental Protection Agency, 1971).

Electrical conductivity was determined using a Barnstead conductivity bridge. The pH was determined with a digital pH meter. An atomic absorption-flame emission spectrophotometer was utilized in the analysis of the cations with sodium and potassium concentrations determined by flame emission, and calcium and magnesium were determined by atomic absorption. These procedures are described in "Analytical Methods for Atomic Absorption Spectrophotometry" (Perkin-Elmer, 1971). Sulfate concentrations were determined by the nitrochromeazo titrimetric method developed by Rasnick and Nakayama (1973). Carbonate and bicarbonate concentrations were determined by titration with 0.01 N sulfuric acid in the presence of phenolpthalein and methyl orange

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(U.S. Salinity Laboratory, 1954). Chloride analysis was completed on a Buchler-Cotlove chloridometer (Cotlove, et al., 1958). Nitrate analyses were done spectrophotometrically (Lambert and Dubois, 1971).

RESULTS AND DISCUSSION

Water Application and Weather Data

The depths of water applied during the 1976 growing season are listed in Table 5 for the surface-irrigated plots and in Table 6 for the trickle-irrigated plots. The last irrigation was on August 20. There was no pre-irrigation in 1976.

The depths of water applied to the cotton during the 1977 growing season are listed in Tables 7 and 8 for the surface- and trickle-irrigated plots, respectively.

The weather data for the years 1975-1977 is presented in Sammis (1980). Pan evaporation data during the main cotton growing season are presented in Table 9 for 1975, 1976 and 1977.

The data in Table 9 show that pan evaporation during the summer of 1977 was higher than during the summers of 1975 and 1976, largely as a result of the high pan evaporation during September 1977. For the months of June, July and August when the cotton is transpiring most actively, the total pan evaporation was 86.8, 84.6 and 86.0 cm, respectively. This indicates that the actual crop water use during these months was fairly constant over the three years.

Soil Salinity In Surface Irrigated Plots

Saturation Extracts--

Soil samples were taken from the surface-irrigated plots and saturation extracts were prepared. The analyses of the saturation extracts are presented in Wierenga (1979). Listed are the electrical conductivities (EC_e) and chloride concentrations (for December 1976 and December 1977) of the saturation extracts as well as the saturation percentages for the soil samples. Calculated salt contents in g/100g soil are also given (see Wierenga, 1977).

In 1976 and 1977 the soil was sampled at three locations per plot in 20 cm depth increments down to 180 cm. Two of the three locations in each plot were over the "old" plots, whle the third locations was over the previously uncultivated area (see Figure 3).

Saturation percentages, chloride concentrations, and electrical conductivities (EC_e) from samples in the first two plot rows down to 80 cm, and from samples in the third plot row at two depths. In December 1976 and in December 1977, these differences in salinity between the three locations had largely disappeared. Out of the 27 electrical conductivity comparisons (9

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TABLE 5. DEPTH OF WATER APPLIED TO THE SURFACE IRRIGATED PLOTS FROM MAY 6 TO AUGUST 20, 1976*

Irrigation Interval	Planned Irrigation Efficiency 100% Plot No	100% Water Applied (cm)	90% Plot No	90% Water Applied (cm)	80% Plot No	80% Water Applied (cm)
1 week	8	46.2	9	56.1	2	65.8
	12	46.2	18	56.1	14	66.3
	26	46.2	24	56.1	28	66.5
2 weeks	7	46.7	1	56.1	4	66.3
	17	46.2	15	55.9	19	66.3
	27	46.2	29	54.9	25	66.3
3 weeks	6	46.5	3	54.1	5	61.5
	13	46.5	11	54.1	16	62.2
	22	46.2	23	54.1	21	61.2
Average		46.3		55.3		64.7

* Does not include rainfall of 8.9 cm over this period.

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TABLE 6. DEPTH OF WATER APPLIED TO THE TRICKLE IRRIGATED PLOTS FROM MAY 6 TO AUGUST 20, 1976*

Irrigation Treatment 0.2 BAR Plot No	0.2 BAR cm	0.7 of Amount at 0.2 BAR Plot No	0.7 of Amount at 0.2 BAR cm
3	40.6	1	42.8
4	50.7	2	42.9
5	48.4	6	42.2
Average	49.0		42.6

* Does not include rainfall of 8.9 cm over this period.

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TABLE 7. DEPTH OF WATER APPLIED TO THE SURFACE IRRIGATED PLOTS FROM APRIL 28 TO AUGUST 19, 1977*

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	Planned Irrigation Efficiency					
	100%		90%		80%	
Irrigation Interval	Plot No	Water Applied (cm)	Plot No	Water Applied (cm)	Plot No	Water Applied (cm)
1 week	8	51.0	9	59.7	2	71.2
	12	50.8	13	60.1	14	69.9
	26	50.2	24	60.3	28	70.0
2 weeks	7	50.2	1	61.2	4	70.5
	17	51.1	15	60.8	19	70.1
	27	51.8	29	59.9	25	71.1
3 weeks	6	52.1	3	60.7	5	69.7
	13	50.1	11	60.1	16	70.3
	22	49.1	23	60.2	21	70.2
Average		50.7		60.3		70.3

* Does not include rainfall of 15.5 cm over this period.

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TABLE 8. DEPTH OF WATER APPLIED TO THE TRICKLE IRRIGATED PLOTS FROM MAY 1 TO SEPTEMBER 1, 1977*

Irrigation Treatment			
0.2 BAR		0.7 of Amount at 0.2 BAR	
Plot No	cm	Plot No	cm
3	48.7	1	37.0
4	50.7	2	38.5
5	51.2	6	36.0
Average	50.2		37.2

* Does not include rainfall of 15.6 cm over this period.

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TABLE 9. PAN EVAPORATION DURING THE SUMMER MONTHS OF 1975, 1976, and 1977

Month	Year 1975 (cm)	 1976 (cm)	 1977 (cm)	Average (cm)
April	23.6	23.6	23.8	23.7
May	28.1	30.0	28.0	28.7
June	33.3	34.0	29.4	32.2
July	27.9	26.8	29.2	28.0
August	25.6	23.8	27.4	25.6
September	17.8	17.6	23.3	19.6
Total	156.3	155.8	161.1	157.8

depths and 3 rows) made between the A, B, and C locations in December 1976, only 3 showed a significant difference (Table 10). Only 4 out of the 27 comparisons of chloride concentration showed significant differences by location in December 1976. In December 1977 there were significant differences by location in 6 out of the 27 comparisons of electrical conductivity and in 4 of the 27 comparisons of chloride concentration and saturation percentage.

Combining the data from the three rows, the analysis showed some significant differences in EC_e for samples taken at the three locations in May 1976 from the 0-20 cm depth. There were no significant differences at the other depths. The combined analysis showed no significant difference in EC_e between samples from the three locations taken in December 1976 and December 1977. Because the difference in EC_e was significant only in the surface soil and had generally disappeared after one irrigation season, the data from the three sample locations within each plot were averaged for the subsequent analysis.

An analysis of variance was performed to determine the effects of irrigation treatments on EC and chloride concentrations. Tables 11, 12, and 13 present the treatments means for EC for May 1976, December 1976, and December 1977, respectively. The treatment means for the chloride concentrations of the saturation extracts are listed in Tables 14 and 15 for December 1976 and 1977, respectively. Treatment means for EC and chloride concentrations are also presented in Figures 4-9.

Table 11 and Figure 4, presenting data from the spring of 1976, show no differences in soil salinity (EC_e), due to irrigation efficiency during the

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TABLE 10. SIGNIFICANT DIFFERENCES IN EC_e, CHLORIDE CONCENTRATION, AND PERCENT SATURATION BETWEEN LOCATIONS I, II, and III WITHIN PLOTS

	EC_e			Chloride			Percent Saturation		
Depth (cm)	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3	Rep 1	Rep 2	Rep 3
May, 1976									
0- 20	**	**	-				**	**	-
20- 40	**	**	-				-	**	-
40- 60	**	**	**				-	*	-
60- 80	**	*	**		no data		-	-	-
80-100	-	-	-				-	-	-
100-120	-	**	-				-	*	-
120-140	-	-	-				-	-	-
140-160	-	-	-				-	-	-
160-180	-	-	-				-	-	-
December, 1976									
0- 20	-	-	**	-	-	-	-	-	-
20- 40	-	-	-	-	**	-	*	**	-
40- 60		-	-	-	*	-	-	**	-
60- 80	-	-	-	**	*	-	-	**	-
80-100	-	**	-	-	-	-	-	**	-
100-120	*	-	-	-	-	-	-	-	-
120-140	-	-	-	-	-	-	-	-	-
140-160	-	-	-	-	-	-	-	-	-
160-180	-	-	-	-	-	-	-	-	-
December, 1977									
0- 20	-	-	-	-	-	-	-	-	-
20- 40	-	-	-	-	-	-	-	-	-
40- 60	**	**	-	*	-	-	-	-	-
60- 80	-	**	-	**	*	-	-	-	-
80-100	-	*	-	-	-	-	-	**	-
100-120	-	**	-	-	**	-	-	*	-
120-140	-	-	-	-	-	-	**	-	-
140-160	-	**	-	-	-	-	-	*	-
160-180	-	-	-	-	-	-	-	-	-

** Significant differences at the 10% confidence interval.
* Significant differences at the 5% confidence interval.

years before 1976. There were, however, significant differences in soil salinity in the 80-160 cm soil depth due to irrigation interval or percent depletion treatments.

In the fall of 1976, soil salinity was significantly affected by irrigation efficiency (Table 12 and Figure 5) and by irrigation interval (Table

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TABLE 11. TREATMENT OF THE EC$_e$ IN THE SURFACE IRRIGATED PLOTS (MAY, 1976)

Item	Depth (cm) 0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	All Depths
	(cm)									
Efficiency Percent										
80	1.80	2.80	3.48	4.70	4.82	3.11	2.31	1.91	1.60	2.95
90	2.14	3.24	3.88	5.29	5.07	3.10	2.12	1.87	1.74	3.16
100	1.82	3.14	4.32	5.16	5.41	3.50	2.43	2.03	1.74	3.28
Interval (weeks)										
1	2.08	3.38	4.00	5.41	5.64**	3.98**	2.86**	2.32*	1.95	3.51
2	1.90	3.02	3.77	5.13	5.34**	3.28**	2.34**	1.97*	1.77	3.19
3	1.79	2.78	3.91	4.62	4.32**	2.46**	1.67**	1.52*	1.35	2.71
All Treatments	1.92	3.06	3.89	5.05	5.10	3.24	2.29	1.94	1.69	3.13

** Significant differences at the 10% confidence interval.
* Significant differences at the 5% confidence interval.

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TABLE 12. TREATMENT MEANS OF THE EC_e IN THE SURFACE-IRRIGATED PLOTS (DECEMBER, 1976)

Item	Depth (cm) 0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	All Depths
	-(cm)-									
Efficiency Percent										
80	2.01	3.05*	4.38*	4.79**	3.13**	2.03	1.74	1.72	1.54	2.71
90	2.42	3.42*	4.87*	5.25**	3.03**	2.10	1.90	2.09	1.94	3.00
100	2.38	3.88*	5.62*	6.31**	4.79**	2.88	2.28	2.18	1.88	3.58
Interval (weeks)										
1	2.65**	4.07**	5.33**	5.88**	4.12**	2.55	2.46*	2.60*	2.09	3.53
2	2.22**	3.34**	5.04**	5.78**	3.86**	2.45	1.80*	1.88**	1.82	3.13
3	1.95**	2.95**	4.50**	4.69**	2.97**	2.01	1.66*	1.50**	1.45	2.63
All Treatments	2.27	3.45	4.96	5.45	3.65	2.34	1.97	2.00	1.79	3.10

** Significant differences at the 10% confidence interval.
* Significant differences at the 5% confidence interval.

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TABLE 13. TREATMENT MEANS OF THE EC_e IN THE SURFACE-IRRIGATED PLOTS (DECEMBER, 1977)

	Depth									All
Item	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	Depths
	(cm)									
Efficiency Percent										
80	2.46**	2.89**	4.55*	4.87**	3.44**	2.18	1.61*	1.76	1.44	2.80
90	2.72**	3.68**	5.57*	5.80**	3.38**	2.22	2.11*	2.01	1.63	3.24
100	3.57**	4.26**	5.59*	6.38**	4.59**	2.63	2.42*	1.86	1.70	3.67
Interval (weeks)										
1	3.34**	4.06**	5.11	5.54	4.15	2.66*	2.06*	2.37**	1.52**	3.50
2	3.23**	3.54**	5.38	6.05	4.03	2.61*	2.42*	1.87**	2.11**	3.47
3	2.18**	3.24**	5.22	5.45	3.22	1.76*	1.66*	1.38**	1.15**	2.81
All Treatments	2.92	3.61	5.24	5.68	3.80	2.34	2.05	1.88	1.59	3.25

** Significant differences at the 10% confidence interval.
* Significant differences at the 5% confidence interval.

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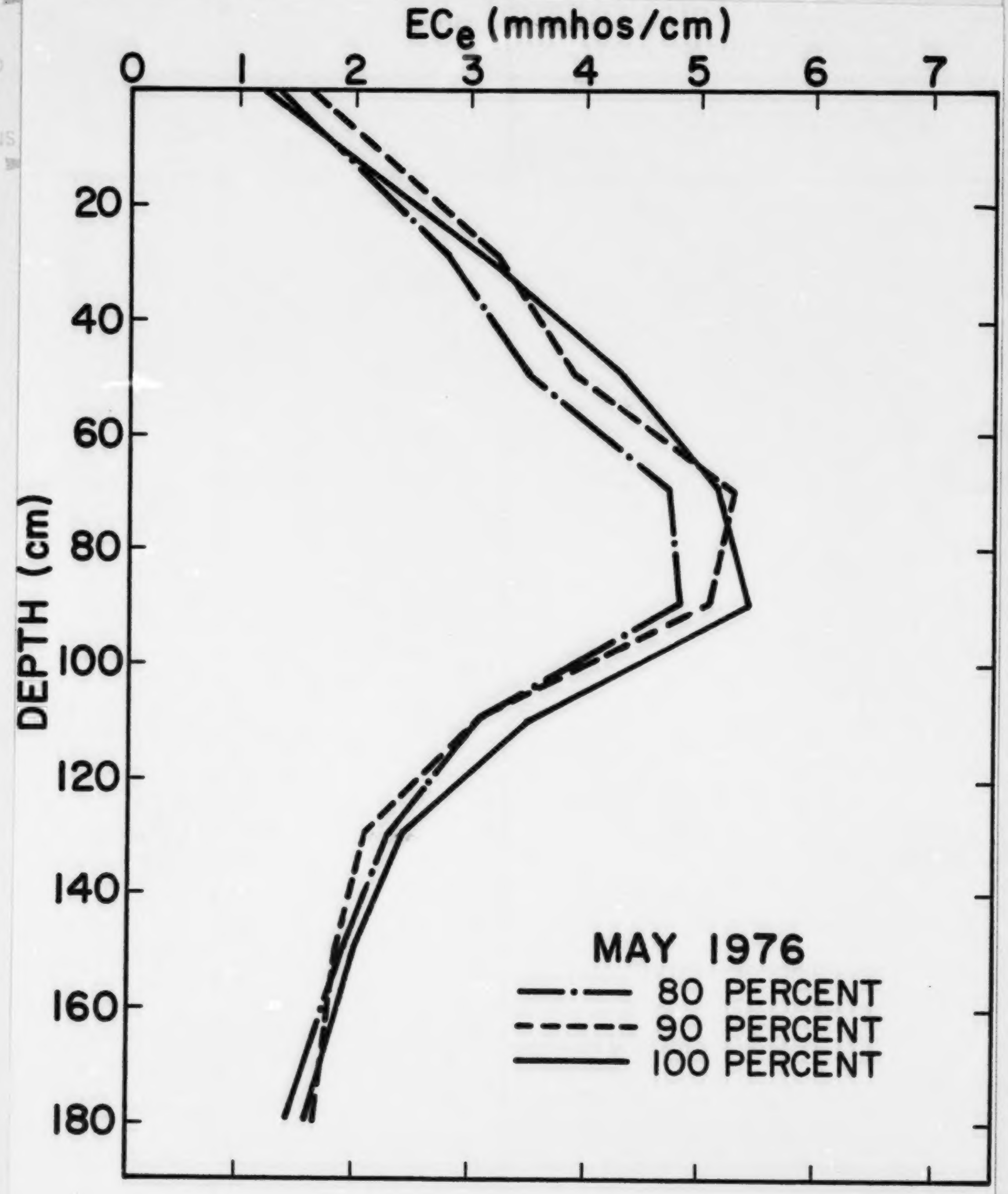

Figure 4. Electrical conductivity of saturation extracts by depth for the 80, 90, and 100 percent irrigation efficiency levels for May 1976.

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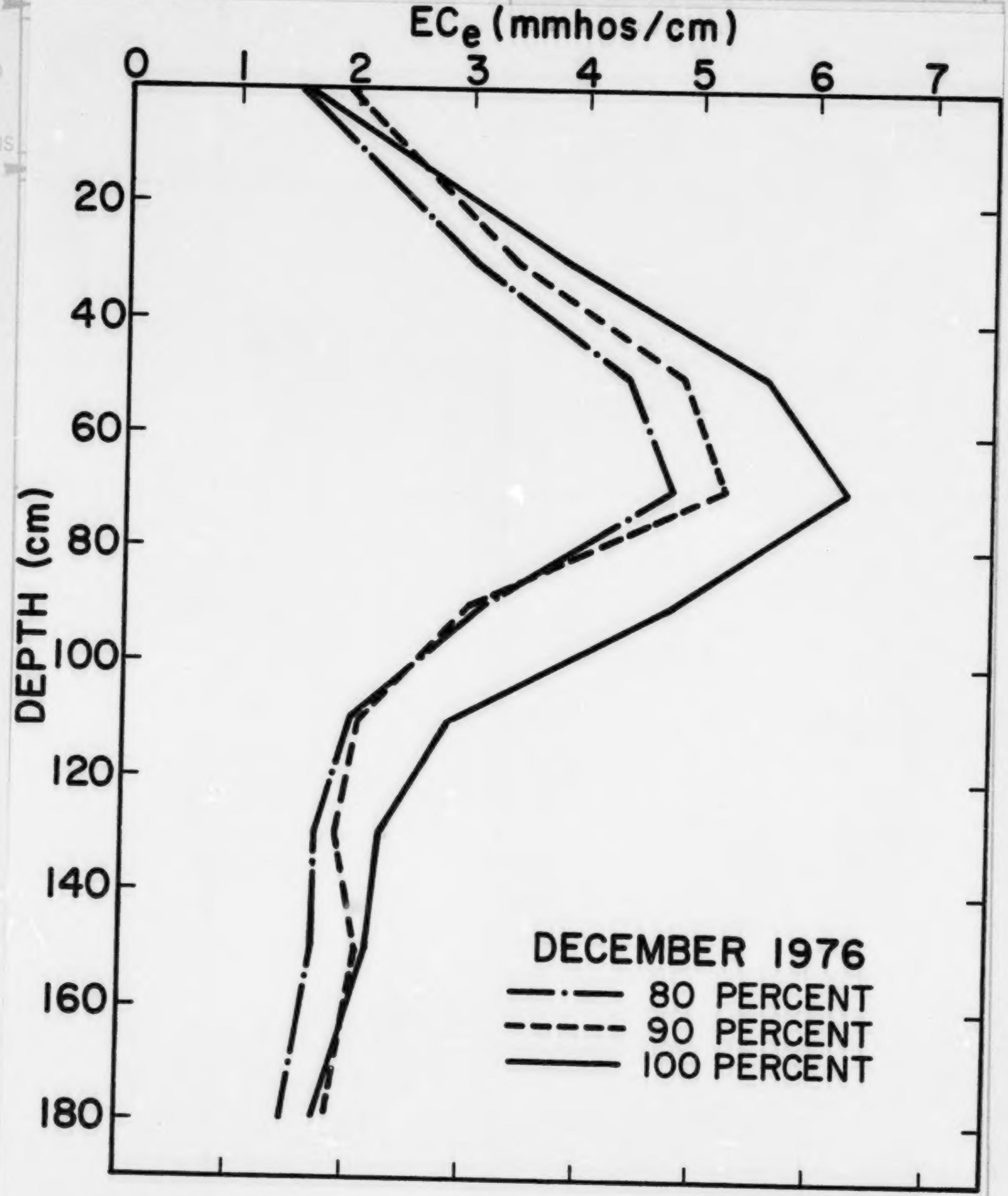

Figure 5. Electrical conductivity of saturation extracts by depth for the 80, 90, and 100 percent irrigation efficiency levels for December 1976.

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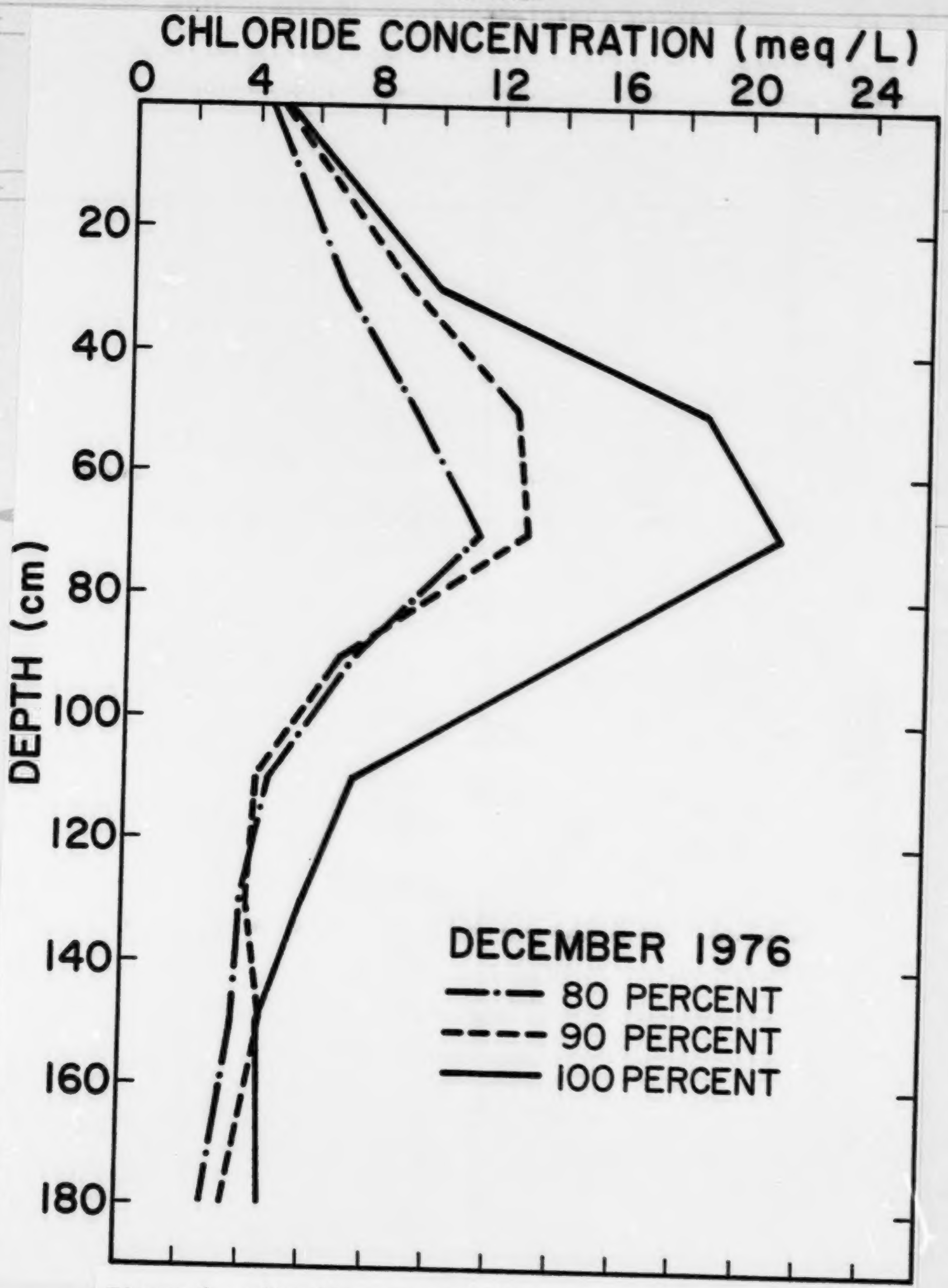

Figure 6. Chloride concentrations of saturation extracts by depth for the 80, 90, and 100 percent irrigation efficiency levels for December 1976.

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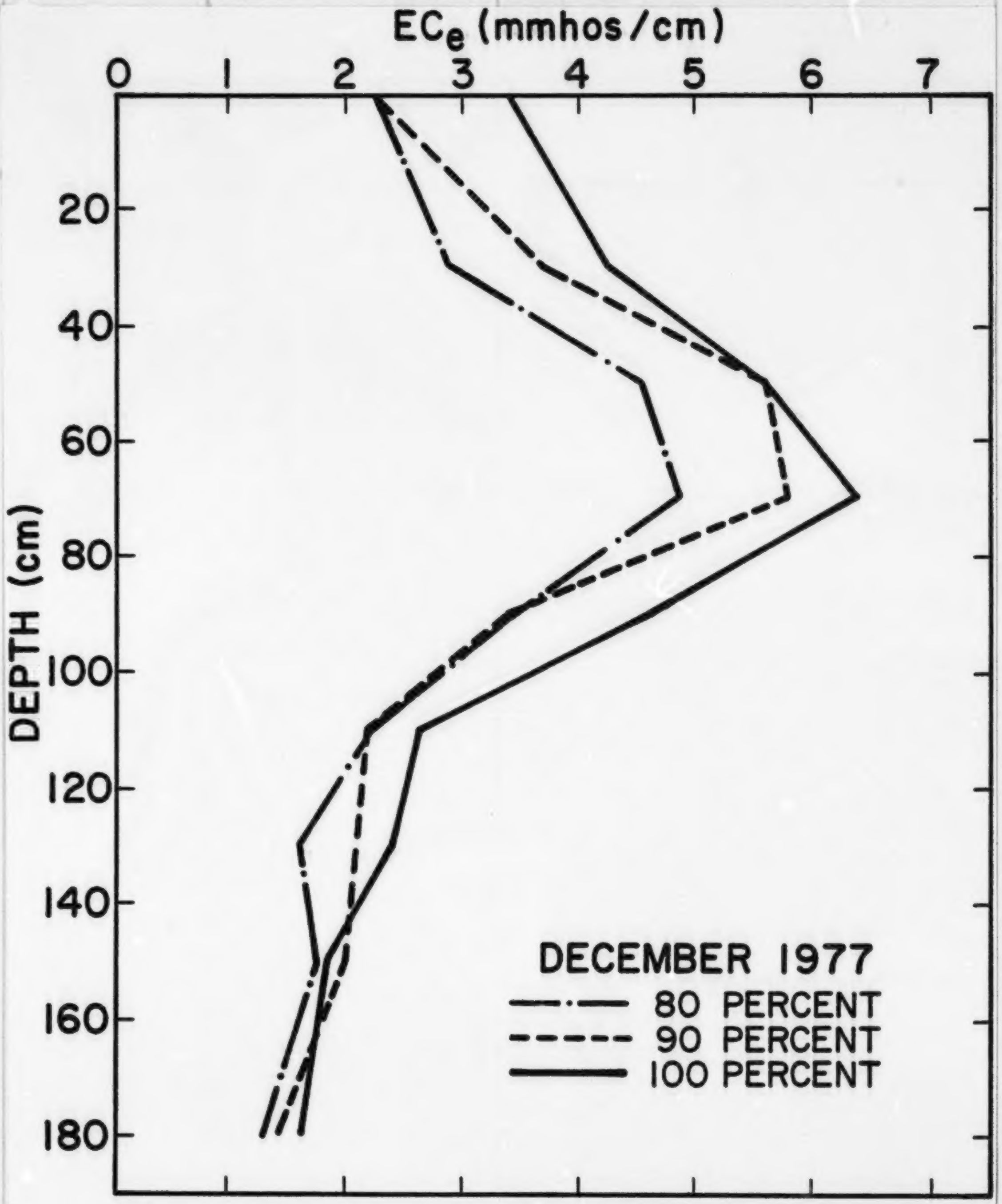

Figure 7. Electrical conductivity of saturation extracts by depth for the 80, 90, and 100 percent irrigation efficiency levels for December 1977.

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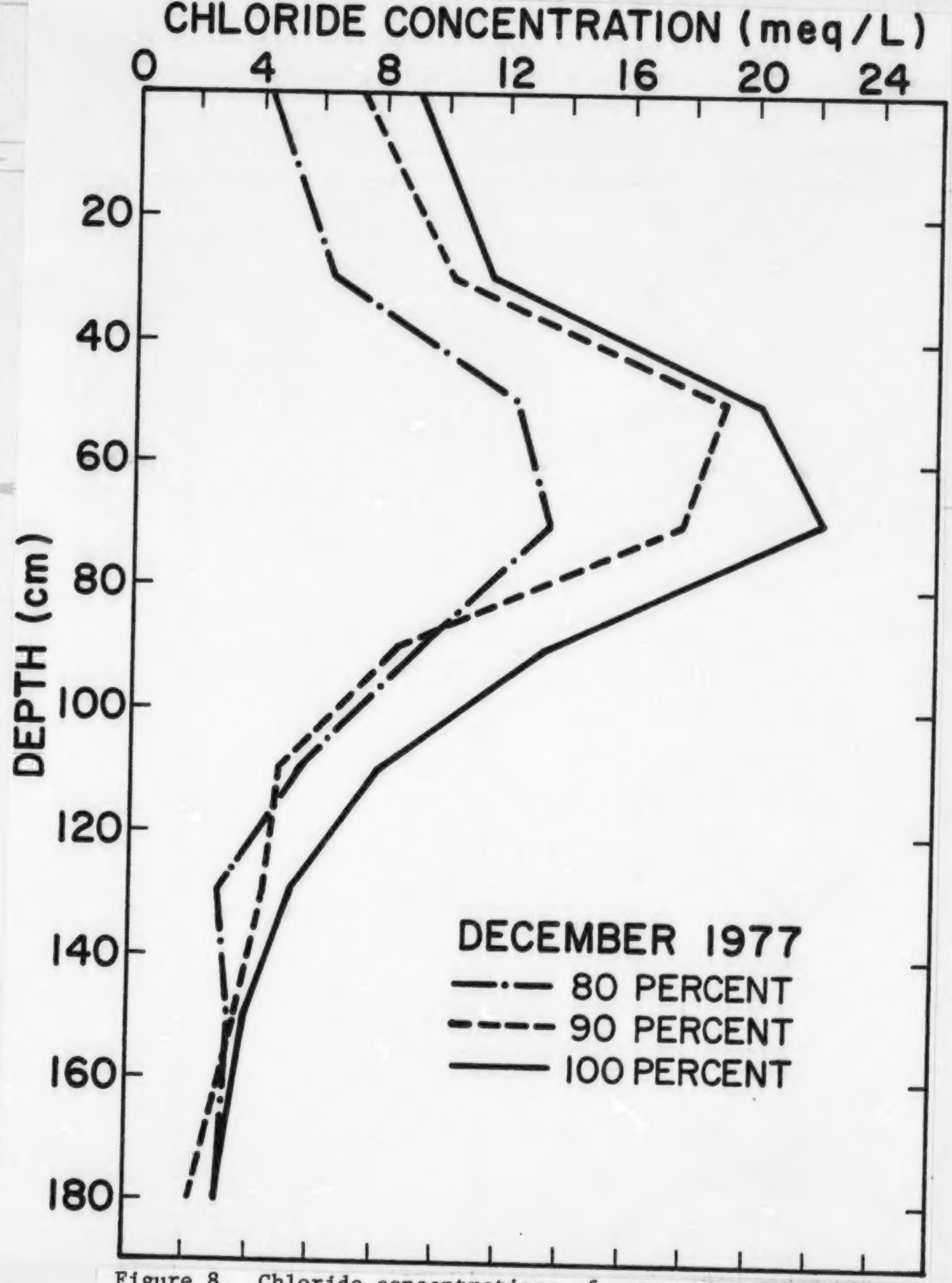

Figure 8. Chloride concentrations of saturation extracts for the 80, 90, and 100 percent irrigation efficiency levels for December 1977.

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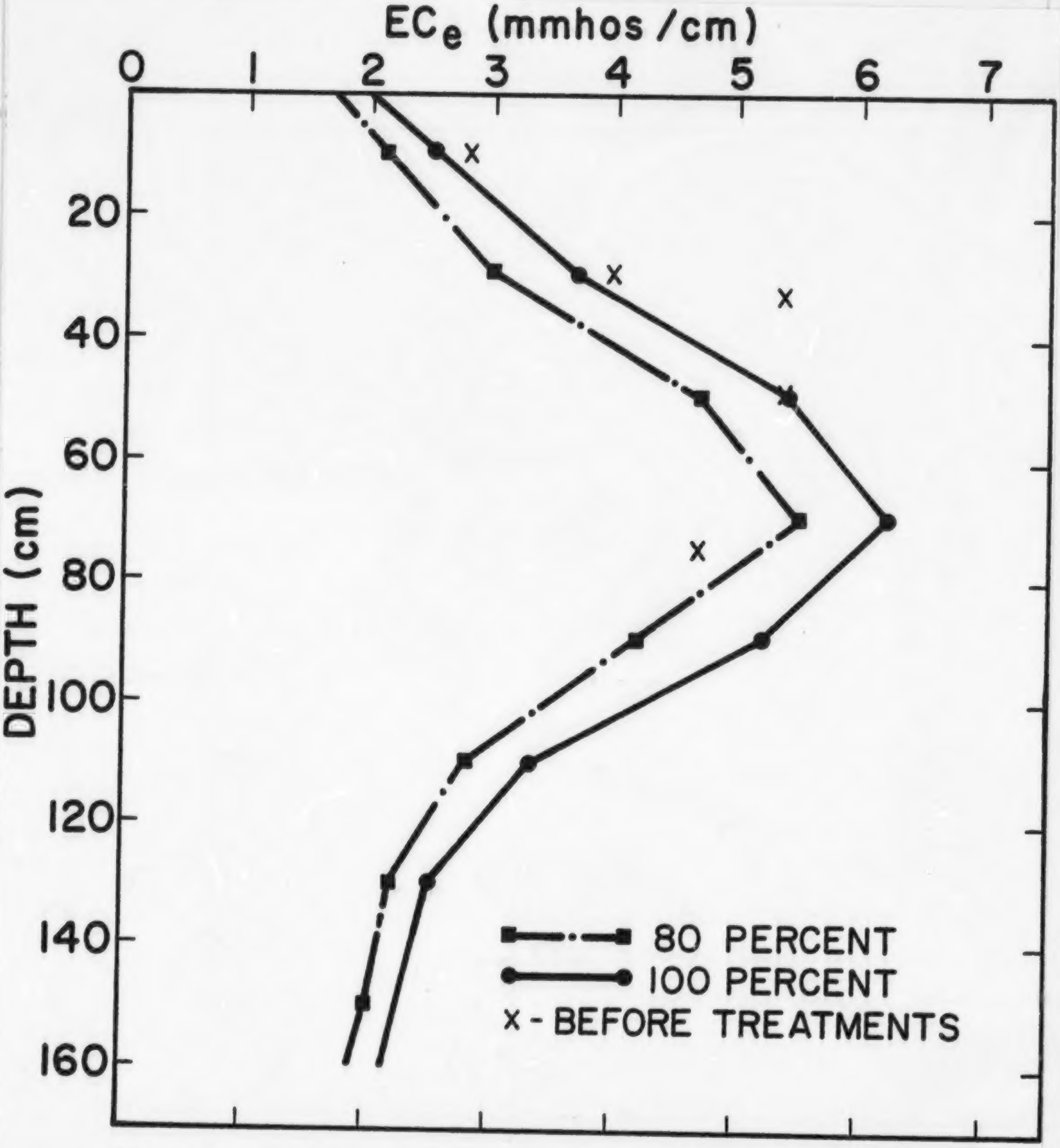

Figure 9. Mean electrical conductivities of saturation extracts for the samples from the 80 and 100 percent irrigation efficiency treatments averaged over the period 1972-1977.

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12). The chloride concentrations of the saturation extracts were also significantly affected by irrigation treatments (Table 14). EC_e and chloride concentrations tended to be highest in the surface soil of the 100 percent efficiency treatment, as expected, and lowest in the 80 percent efficiency treatment. The effects of irrigation interval appear to be restricted to the upper 40 to 60 cm soil profile.

Irrigation efficiency had no significant effects on EC_e or chloride concentration in the subsoil (140-180 cm) indicating that improving irrigation efficiency has no immediate effect on the quality of percolation water.

Tables 13 and 15 and Figures 7 and 8 show the response in EC_e and chloride concentration to treatments as measured in the fall of 1977. The results are similar to those of 1976 with the effects of irrigation efficiency and interval most pronounced in the surface soil. Again, irrigation interval had a significant impact on the subsoil salinity (Table 13), but not on the subsoil chloride concentration (Table 15). It is assumed that the significant differences in the EC_e at 80-160 cm soil depth due to irrigation intervals in May 1976 are a result of previous irrigation treatments. As reported before (Wierenga, 1977), irrigation depletion or interval had five times the effect that efficiency had on the EC_e in plots irrigated at different efficiencies and intervals during 1976, 1973, and 1974.

Table 16 presents the mean EC_es as measured in the fall of 1972, 1973, 1974, 1976, and 1977 for plots irrigated near 100 percent efficiency. This same information is presented in Table 17 for the 80 percent efficiency irrigation treatment. A gradual increase in mean EC_e is shown between 1972 and 1974 and from 1976 to 1977 (last column of Tables 16 and 17). Between 1974 and 1976, there was a decrease in soil salinity, probably due to over-irrigation of the wheat crop in the spring of 1975 and of the barley crop during the 1975/76 winter. The mean EC_e values, averaged over the years 1972 to 1977 for the 100 percent and 80 percent efficiency treatments, are plotted in Figure 10. Averages of the EC_e values for all plots before the start of treatments are also presented. The latter data were available for four depths only.

Figure 9 shows the influence of leaching on soil salinity. The 80 percent efficiency treatment, which received 20 percent more water than the 100 percent treatment, has a lower overall salt content than the 100 percent efficiency treatment (mean EC_e for all depths is 3.3 mmhos/cm for the 80 percent treatment, versus 3.9 mmhos/cm for the 100 percent treatment). Surprisingly, the average salt distribution in the surface soil did not change much from the salt distribution as measured before the start of irrigation treatments. This indicates that there was just enough leaching, even in the 100 percent efficiency plots, to prevent a drastic increase in soil salinity in these plots. Some leaching of the 100 percent efficiency plots may have occurred during pre-irrigation in 1972-1974, and during irrigation of the wheat and barley crops in 1975. Table 18 lists the EC_e values averaged over all treatments by depth and year. The general trend is the same as for the data in Tables 16 and 17.

Figures 4-9 show a nearly linear increase with depth down to the 60-80

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TABLE 14. TREATMENT MEANS OF CHLORIDE CONCENTRATIONS (meq/ℓ) IN SATURATION EXTRACTS FROM SURFACE-IRRIGATED PLOTS (DECEMBER, 1976)

Item	Depth									All Depths
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	
	(cm)									
Efficiency Percent										
80	5.27*	7.02**	9.38**	11.48**	7.47**	4.81*	3.87	3.72	3.10	6.24
90	6.23*	9.12**	12.63**	13.09**	7.10**	4.39*	4.03	4.57	3.89	7.23
100	6.69*	10.07**	18.91**	21.25**	14.17**	7.45*	5.82	4.39	4.57	10.37
Interval (weeks)										
1	7.55**	10.88**	15.01	15.83	9.91	5.61	5.74	4.78	3.42	8.75
2	6.08**	8.67**	13.66	16.47	11.16	5.80	4.22	4.55	4.47	8.37
3	4.56**	6.66**	12.24	13.25	7.66	5.24	3.76	3.37	3.66	6.71
All Treatments										
	6.06	8.73	13.64	15.27	9.58	5.55	4.58	4.23	3.85	7.95

* Significant differences at the 5% confidence level.
** Significant differences at the 10% confidence level.

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TABLE 15. TREATMENT MEANS OF CHLORIDE CONCENTRATIONS (meq/ℓ) IN SATURATION EXTRACTS FROM SURFACE-IRRIGATED PLOTS (DECEMBER, 1977)

Item	Depth 0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	All Depths
	(cm)									
Efficiency Percent										
80	5.11**	6.45**	12.38**	13.49**	9.37*	5.56	3.03	3.41	3.12	6.88
90	8.24**	10.26**	19.24**	17.85**	8.62*	4.84	4.36	3.58	2.58	8.84
100	9.99**	11.61**	20.27**	22.34**	13.48*	8.19	5.32	3.89	3.25	10.93
Interval (weeks)										
1	0.97**	11.02**	17.41	15.47	10.69	6.91	3.77	4.94	2.55	9.08
2	9.60**	9.42**	17.53	19.62	10.60	6.97	5.18	3.38	4.31	9.62
3	4.78**	7.87**	17.21	18.60	10.18	4.70	3.77	2.56	2.09	7.97
All Treatments	7.78	9.44	17.38	17.90	10.49	6.19	4.24	3.63	2.99	8.89

* Significant differences at the 5% confidence level.
**Significant differences at the 10% confidence level.

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TABLE 16. MEAN EC_e BY DEPTH AND YEAR FOR PLOTS IRRIGATED NEAR 100% EFFICIENCY

Date	Depth								All Depths
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	
	(cm)								
Dec. 1972	1.9	3.2	5.1	5.3	4.3	2.9	2.3	2.2	3.4
Dec. 1973	2.1	2.7	5.0	6.2	5.9	3.5	2.6	2.6	3.8
Dec. 1974	2.5	4.2	5.8	6.7	6.4	4.5	3.1	2.5	4.5
Dec. 1976	2.4	3.9	5.6	6.3	4.8	2.9	2.3	2.2	3.8
Dec. 1977	3.6	4.3	5.6	6.4	4.6	2.6	2.4	1.9	3.9
All Years	2.5	3.7	5.4	6.2	5.2	3.3	2.5	2.3	3.9

TABLE 17. MEAN EC_e BY DEPTH AND YEAR FOR PLOTS IRRIGATED NEAR 80% EFFICIENCY

Date	Depth								All Depths
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	
	(cm)								
Dec. 1972	1.7	2.5	4.5	5.0	4.9	3.6	2.6	1.7	3.3
Dec. 1973	1.9	2.4	4.7	5.8	4.7	3.2	2.8	2.7	3.5
Dec. 1974	2.6	3.9	5.2	6.8	4.8	3.1	2.4	2.2	3.9
Dec. 1976	2.0	3.1	4.4	4.8	3.1	2.0	1.7	1.7	2.9
Dec. 1977	2.5	2.9	4.6	4.9	3.4	2.2	1.6	1.8	3.0
All Years	2.1	3.0	4.7	5.5	4.2	2.8	2.2	2.0	3.3

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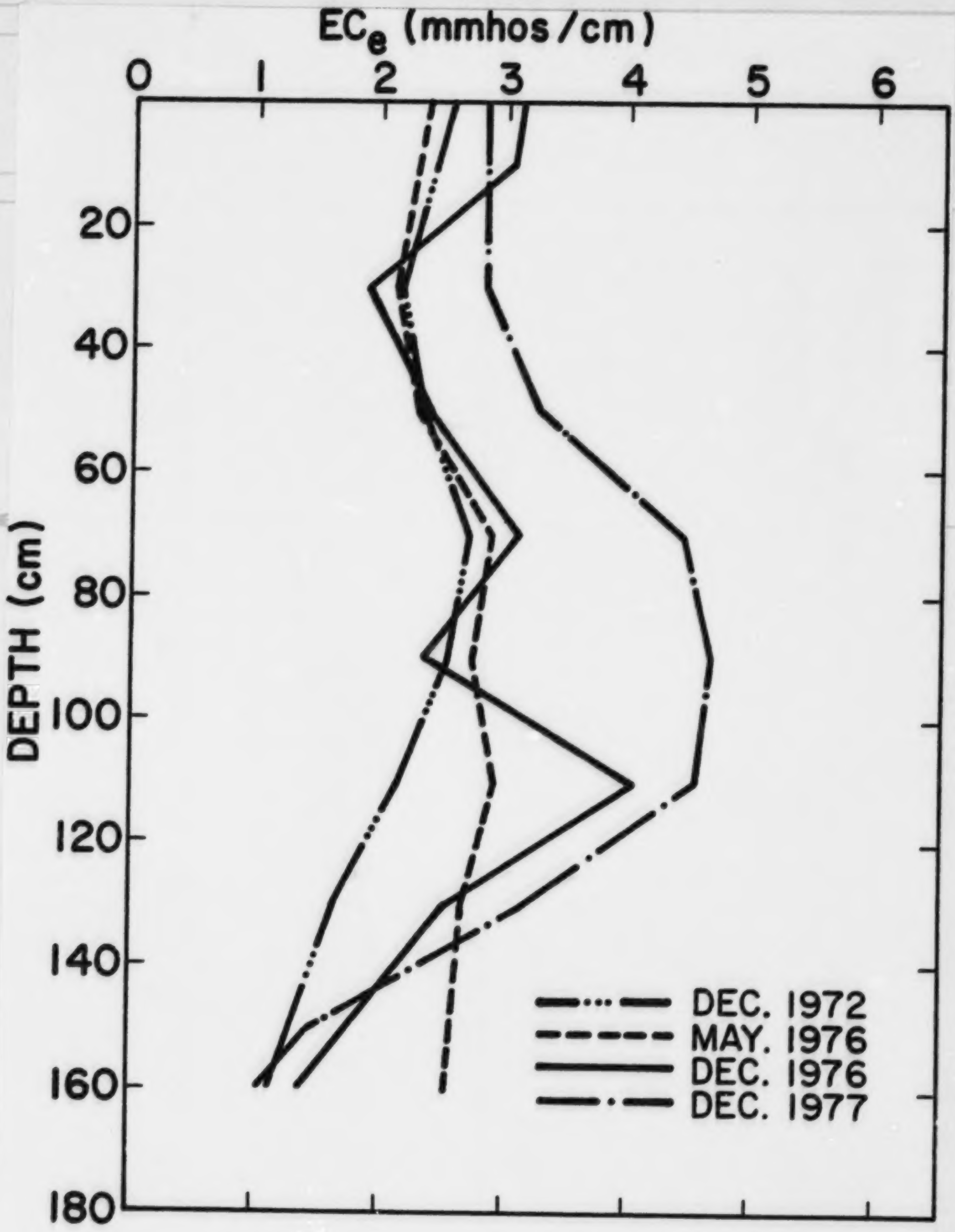

Figure 10. Mean salt distributions in the trickle-irrigated plots for December 1972, May 1976, December 1976, and December 1977.

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TABLE 18. MEAN EC_e BY DEPTH AND YEAR FOR THE SURFACE-IRRIGATED PLOTS

Date	Depth 0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	All Depths
	(cm)								
Dec. 1972	1.84	2.95	4.96	5.24	4.88	3.38	2.65	2.25	3.52
Dec. 1973	2.05	2.63	4.81	6.05	5.30	3.33	2.62	2.48	3.66
Dec. 1974	2.47	4.05	5.50	6.65	5.74	3.70	2.74	2.11	4.12
Dec. 1976	2.27	3.45	4.96	5.45	3.65	2.34	1.97	2.00	3.26
Dec. 1977	2.92	3.61	5.24	5.68	3.80	2.34	2.05	1.88	3.44
All Years	2.31	3.34	5.09	5.81	4.67	3.02	2.41	2.14	3.60

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cm depth, and then a decrease. The increase in salinity with depth is a result of water uptake by roots. Near the surface only a small fraction of the applied water is taken up. Most of this water moves to the soil below resulting in extensive leaching of the soil at this depth. From the surface on down, the amount of water that is not taken up, (i.e. is available for leaching) gradually decreases. Since little of the salt in the irrigation water is taken up, the salt concentration in the soil increases. When this process goes on for a fairly long time, a linear or curvilinear increase in soil salinity with depth may be expected (Ayers and Westcot, 1976).

Below the root zone, the concentration in the saturation extracts should remain approximately constant with depth in uniform soils. Figures 4-9 show that the EC_e values decrease with depth below 80 cm due to the textural changes in the soil profile. The surface soil (0-80 cm) at the site is a clay loam while the subsoil is sandy. As a result, the volume of water required to make saturation extracts changed with depth, varying from an average of 66.6 ml per 100 g of soil at the 20 to 60 cm depth to 26.7 ml per 100 g of soil at the 140 to 180 cm depth. Based on measured mean field water contents (Wierenga, 1979) and bulk density values of 1.4 and 1.6 g/cm for the clay loam and sand, respectively, the mean EC_e of the soil solution at the 40-60 cm depth for the 80 percent efficiency treatment (see Table 17) is 4.7 x 2.2 = 10.33 mmhos/cm. At the 140-160 cm depth, the EC_e of the soil solution is 4.54 x 2.0 = 9.0 mmhos/cm. The decrease in EC_e with depth below 60 cm, then, is much less than Figures 4-9 would indicate. In fact, assuming steady state conditions and some leaching, one would expect a fairly constant EC of the soil slution (not a constant EC_e) with depth below the root zone.

Table 19 presents the mean EC_e values for plots irrigated at 25 percent depletion (or once a week) from 1972 to 1977. Table 20 presents this data for the 75 percent depletion (or once every three weeks) treatment. The EC values averaged over the years of the experiment are also presented for each depth interval. Comparing Tables 19 and 20 with Tables 16 and 17, and Figure 9, it appears that the differences in soil salinity between the one and three week irrigation treatments are about the same as between the 80 and 100 percent efficiency treatments. This indicates that when limited amounts of water are available, less frequent irrigation (once every three weeks) causes less salt accumulation than frequent irrigation.

Soil Solution Samples

In 1976 soil solution samplers (Soil Moisture Equipment Company, Santa Barbara, California) were installed at two locations within each plot with their tips 30 cm below the clay-loam overlying the sand in each plot. Samples were collected throughout the 1976 growing season and analyzed for chloride concentration only. The results of the analyses are presented in Table 21. The data show considerable variation with time and with location. It is not clear what caused the variation in chloride concentration with the time of year. In some plots, the chloride concentration increased (e.g. plot 3A) while in others it decreased regardless of treatment. The spatial variation in chloride concentration of the soil solution samples is rather pronounced and of the same magnitude as that of the saturation extracts. The mean chloride concentration of the soil solution from the A-plots is 20.8

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TABLE 19. MEAN EC_e FOR PLOTS IRRIGATED AT 25% DEPLETION (OR ONCE A WEEK) BY DEPTH AND YEAR

Date	Depth								All Depths
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	
	(cm)								
Dec. 1972	2.3	3.3	5.6	6.1	6.3	4.4	3.2	2.6	4.2
Dec. 1973	2.1	2.9	5.3	6.5	5.3	3.5	3.1	3.4	4.0
Dec. 1974	2.5	4.3	5.3	6.6	5.4	3.7	2.6	2.1	4.1
Dec. 1976	2.7	4.1	5.3	5.9	4.1	2.6	2.5	2.6	3.7
Dec. 1977	3.3	4.1	5.1	5.5	4.2	2.7	2.1	2.4	3.7
All Years	2.6	3.7	5.3	6.1	5.1	3.4	2.7	2.6	3.9

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TABLE 20. MEAN EC_e FOR PLOTS IRRIGATED AT 75% DEPLETION (OR ONCE EVERY THREE WEEKS) BY DEPTH AND YEAR

Date	Depth								All Depths
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	
	(cm)								
Dec. 1972	1.6	2.9	4.4	4.8	4.0	2.6	2.3	2.3	3.1
Dec. 1973	1.9	2.2	4.4	5.3	4.4	2.7	2.3	1.6	3.1
Dec. 1974	2.6	3.7	5.5	6.0	5.0	3.3	2.4	2.0	3.8
Dec. 1976	2.0	3.0	4.5	4.7	3.0	2.0	1.7	1.5	2.8
Dec. 1977	2.2	3.2	5.2	5.5	3.2	1.8	1.7	1.4	3.0
All Years	2.1	3.0	4.8	5.3	3.9	2.7	2.1	1.8	3.2

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TABLE 21. CHLORIDE CONCENTRATIONS (meq/ℓ) OF SOIL SOLUTION SAMPLES WITHDRAWN THROUGH SUCTION CUPS PLACED 30 CM BELOW THE CLAY-LOAM SOIL IN THE SURFACE-IRRIGATED PLOTS

Date	PLOT 1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
	meq/ℓ									
1976										
6-21									10.8	10.4
6-25			18.6						10.2	10.8
6-28			14.3				3.4	15.6	10.3	10.4
7-11	12.1		12.2	27.6	12.8	13.1	3.4		16.6	12.0
7-18	10.1	69.9	11.7	28.2	12.2		7.0		19.6	
7-25	8.6	63.8	11.2	26.8	19.3		7.8		18.2	19.0
8-1	7.7	73.7	10.4	26.9	24.4	12.0	8.7	24.4	13.1	22.3
8-8	7.8	58.6	9.7	26.2	27.0		9.9	25.0	12.4	27.3
8-15	8.8	58.9	9.5	33.1	22.4	13.4	12.3		10.3	43.5
8-25	8.9	49.7	8.7		36.4	14.2	15.8		7.7	46.9
8-31			8.6	39.4	32.5	14.8	15.5		5.1	54.4
Mean	9.2	62.4	11.5	29.7	23.4	13.5	9.3	21.7	12.2	25.7
Std. Dev.	1.5	8.6	3.0	4.8	8.6	1.1	4.6	5.3	4.4	16.8

Date	PLOT 6A	6B	7A	7B	8A	8B	9A	9B	11A	11B
	meq/ℓ									
1976										
6-23					27.2					
6-25	9.5					26.7				
6-28	7.0	35.0				24.8				
7-6									11.8	
7-11	7.5	34.1		24.0		25.1	15.9	44.6		
7-13									10.5	47.8
7-18	33.3	34.8	16.6	23.8		25.3	14.8	44.2		
7-20									11.1	
7-25	8.5	35.9		25.1		24.1	12.4	41.9		
8-1	16.9	38.7				24.4	11.3	43.1		
8-3									9.2	
8-8	28.2	42.1		33.1	46.0	23.6	10.8	42.4		
8-10									7.8	40.3
8-15	32.5	65.0				24.9	12.2	47.2		
8-25	33.9	68.5				24.5	11.5		9.2	44.7
8-31	34.4					24.8		57.7		47.7
Mean	21.2	44.6		26.5	41.4	24.8	12.7	45.9	9.9	45.1
Std. Dev.	12.3	14.1		4.44	12.5	0.8	1.9	5.5	1.5	3.5

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TABLE 21. (continued)

Date	PLOT 12A	12B	13A	13B	14A	14B	15A	15B	16A	16B
	meq/ℓ									
1976										
6-20									16.6	
6-25										14.9
6-30					18.2	22.5		32.3	40.4	14.8
7-6					13.6	22.0		28.7	42.9	14.9
7-13	24.6		30.0	67.4	12.0	23.7		27.5	35.7	27.5
7-20	20.1		22.1	58.9	13.3	22.3		26.5	36.7	34.3
7-27	39.4		18.6	58.7	12.7	24.7		33.6	36.2	36.7
8-3	20.1		30.2	53.0	11.4	25.4			37.9	34.4
8-10	20.7	26.9	31.6	47.3		23.9		36.9		31.1
8-25	24.0	33.3	28.7	51.2	8.2	27.1		39.3		27.9
8-31		26.4	29.4	50.9	7.1	24.7		38.9	43.2	28.1
Mean	24.8	28.9	27.2	55.3	12.1	23.9		33.0	36.2	26.5
Std. Dev.	7.4	3.9	4.9	6.8	3.4	1.7		5.1	8.4	8.6

Date	PLOT 17A	17B	18A	18B	19A	19B	21A	21B	22A	22B
	meq/ℓ									
1976										
6-30				43.7						
7-2							10.2	4.8		5.1
7-6				36.7	29.5					
7-8							10.2	5.0	12.7	5.5
7-13	66.2		10.7	38.1	26.2	13.4				
7-15								3.8	15.5	5.5
7-18									22.6	
7-20	70.9		9.5	38.0	26.5	27.5				
7-22							7.6	4.4	25.5	
7-27	79.2		9.5	38.0	23.2	27.6				
7-29							7.2		24.8	
8-3	71.0		9.2	33.8	23.8	29.2				
8-5							5.5	4.3	31.6	
8-10	63.5		11.6	30.6	22.8	29.2				
8-19							4.7	4.6	33.8	
8-25	58.9		16.5		14.6					
8-27							4.8		30.3	
8-31			15.8	32.2	19.2					
Mean	68.3		11.8	36.4	20.3	25.4	7.2	4.5	24.6	5.4
Std. Dev.	7.1		3.1	4.1	9.3	6.8	2.3	0.4	7.5	0.2

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TABLE 21. (Continued)

Date	23A	23B	24A	24B	25A	25B	26A	26B	27A	27B
					PLOT					
	meq/ℓ									
1976										
6-23						7.2				
6-25		5.1					41.8			
7-2				4.2	30.9	6.5	15.7	5.7		
7-8	6.8	7.6		4.7	27.0	6.9	21.3	5.6		15.0
7-15	8.4	6.9	9.2	3.7	22.8	6.9	17.3	6.3		13.3
7-18	6.3									
7-22	6.0	6.7		4.0	25.1	7.2	19.4	5.4		13.3
7-29	5.8	6.8	6.9	14.9	25.4	7.7	19.8	5.6	17.8	12.3
8-5	6.5		6.6	5.9	27.1		17.6	5.2	19.3	
8-19	6.3		6.8	9.9	31.8	7.1	29.7	5.5	35.2	15.7
8-27	6.0	6.0	6.3	10.1	32.1	7.0	22.4		32.6	15.4
Mean	6.5	6.5	7.2	7.2	27.8	7.1	22.8	5.6	26.2	14.2
Std. Dev.	0.8	0.9	1.2	4.1	3.5	0.4	8.2	0.4	9.0	1.4

Date	28A	28B	29A	29B
	PLOT			
	meq/ℓ			
7-2		14.9		
7-15	7.8			71.1
7-22	26.0			68.5
7-29	29.0		28.4	67.4
8-5			26.3	61.4
8-19	19.8		28.4	61.8
8-27	16.5		26.4	62.1
Mean	19.8		27.4	65.4
Std. Dev.	8.3		1.2	4.2

Mean of samples from A-plots = 20.83 meq/ℓ; Std. Dev. = 13.64.
Mean of samples from B-plots = 27.39 meq/ℓ; Std. Dev. = 17.88.
Overall mean = 24.10 meq/ℓ; Std. Dev. = 16.06.

meq/ℓ (Std. Dev. = 13.6) versus 27.4 meq/ℓ (Std. Dev. = 17.9) for the B-plots. The overall mean is 24.1 meq/ℓ, with a standard deviation of 16.1. The average chloride concentration of the irrigation water is 2.66 meq/ℓ. This represents a ninefold increase (24.1/2.66) in chloride concentration of the percolation water as compared to the chloride concentration of the irrigation water. Assuming steady state conditions, this would imply a leaching factor (depth of irrigation water divided by depth of drainage water) of 2.66/ 24.1 = 0.11. Previously, a leaching factor of 0.10, based on the average electrical conductivity of the irrigation water was calculated (Wierenga, 1977).

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Separating the mean chloride concentrations in Table 21 by treatment, it is found that the average chloride concentrations for the 80, 90, and 100 percent efficiency treatments were 18.9, 24.9, and 28.8 meq/ℓ, respectively. Based on these concentrations for the 1 week, 2 week, and 3 week irrigation interval treatments were 21.6, 29.6 and 22.0 meq/ℓ, respectively.

Soil Salinity in Trickle-Irrigated Plots

Analyses of the saturation extracts of soil samples from the trickle plots are presented in Wierenga (1979). Trickle plot soil samples were taken immediately below the trickle lines and also at the mid-point between trickle lines. In order to be able to better compare the salinity distributions from one year to another, and in order to compute a salt balance, the salt contents in grams per 100 grams of soil were calculated. This calculation was based on the saturation percentage of each sample and the electrical conductivity of the saturation extract (Wierenga, 1977).

Figure 10 shows the salt distributions in December 1972, May 1976, December 1976, and December 1977. The electrical conductivities plotted are mean values, averaged over treatments and locations (below the trickle line and between the trickle lines). The data show a significant increase in soil salinity between 1972 and 1977, most pronounced in the subsoil from about 30 cm down to about 130 cm. It is not known why the increase in soil salinity is greater for the period December 1976 to December 1977 than during any previous periods as the same sampling technique was used from year to year. The preparation of saturation extracts by different technicians from year to year may have caused some variation. However, when the salt contents were plotted in grams per 100 grams (eliminate differences in saturation extract preparation) versus depth, a figure very similar to Figure 10 was obtained.

Table 22 lists soil salinity values expressed in grams per 100 grams of soil, for the years 1972 to 1977. The average soil salinity increased from 0.96 gram per 100 grams in 1972, to 0.150 gram per 100 grams in 1977, a 65 percent increase. For the wet (0.2 BAR) treatment, the increase in mean salt content was about 25 percent and for the dry treatment (0.6 BAR in the first three years, and 0.7 x the amount of water on the 0.2 BAR treatment the first two years) about 110 percent.

The salinity distribution by irrigation treatments for December 1977 is shown in Figure 11. This figure shows the cumulative effect of applying about 30 percent less irrigation water to the dry treatment. Even though the total amount of water applied to the wet (0.2 BAR) treatment was close to the estimated consumptive use, enough leaching took place to prevent any large increase in soil salinity in this treatment. Over a five year period, the increase in soil salinity was only 25 percent and the average amount of irrigation water applied was 42 cm/year. It appears, then, that soil salinity can be kept at a fairly constant level with trickle-irrigation, even with minimum use of water.

Figure 12 shows the salt distributions below the trickle lines and in between the trickle lines for December 1977. The data plotted are averaged over the treatments. As expected, soil salinity was higher in between the

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TABLE 22. SOIL SALINITY (g/100 g soil) FOR SAMPLING LOCATIONS BELOW AND BETWEEN TRICKLE LINES AS A FUNCTION OF DEPTH AND YEARS

Location	Depth 0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	All Depths
	(cm)								
December 1972									
Below	0.12	0.14	0.11	0.11	0.11	0.09	0.06	0.03	0.096
Between	0.18	0.14	0.11	0.10	0.09	0.08	0.04	0.03	0.096
December 1973									
Below	0.10	0.12	0.11	0.12	0.13	0.13	0.06	0.04	0.101
Between	0.10	0.11	0.12	0.12	0.14	0.13	0.07	0.05	0.105
December 1974									
Below	0.07	0.08	0.11	0.13	0.17	0.19	0.17	0.08	0.125
Between	0.12	0.07	0.20	0.15	0.19	0.19	0.14	0.08	0.142
May 1976									
Below	0.09	0.10	0.14	0.08	0.14	0.17	0.14	0.10	0.120
Between	0.15	0.16	0.15	0.13	0.15	0.15	0.14	0.09	0.140
December 1976									
Below	0.15	0.09	0.11	0.12	0.14	0.18	0.09	0.08	0.120
Between	0.21	0.14	0.16	0.14	0.15	0.19	0.10	0.05	0.143
December 1977									
Below	0.09	0.14	0.16	0.22	0.21	0.22	0.11	0.07	0.153
Between	0.23	0.20	0.17	0.18	0.22	0.16	0.11	0.03	0.163
All Years									
Below	0.103	0.111	0.123	0.130	0.150	0.163	0.105	0.067	0.119
Between	0.165	0.137	0.152	0.137	0.157	0.150	0.100	0.055	0.132

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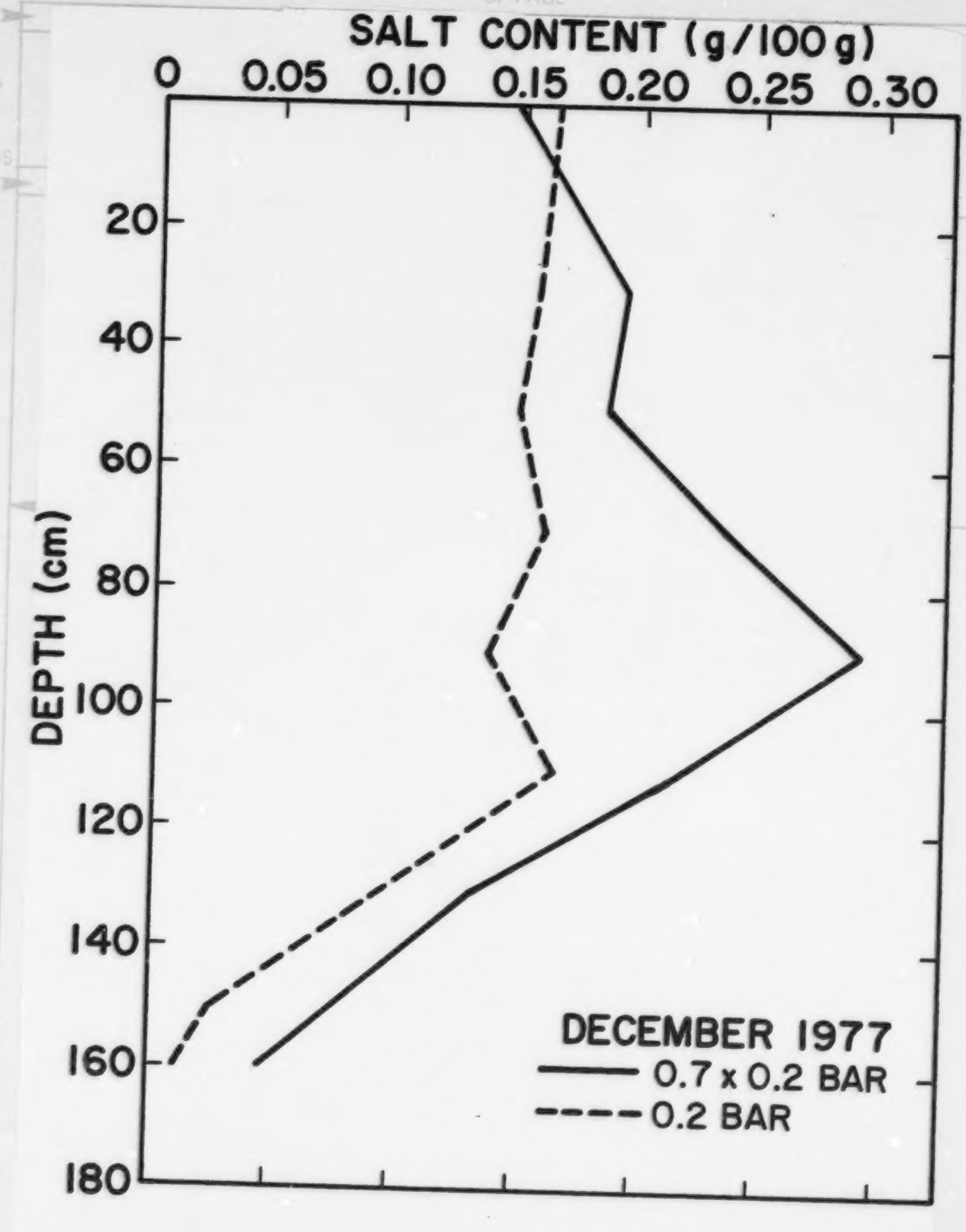

Figure 11. Salt distributions (g/100g soil) in trickle plots irrigated with different amounts of water (December 1977).

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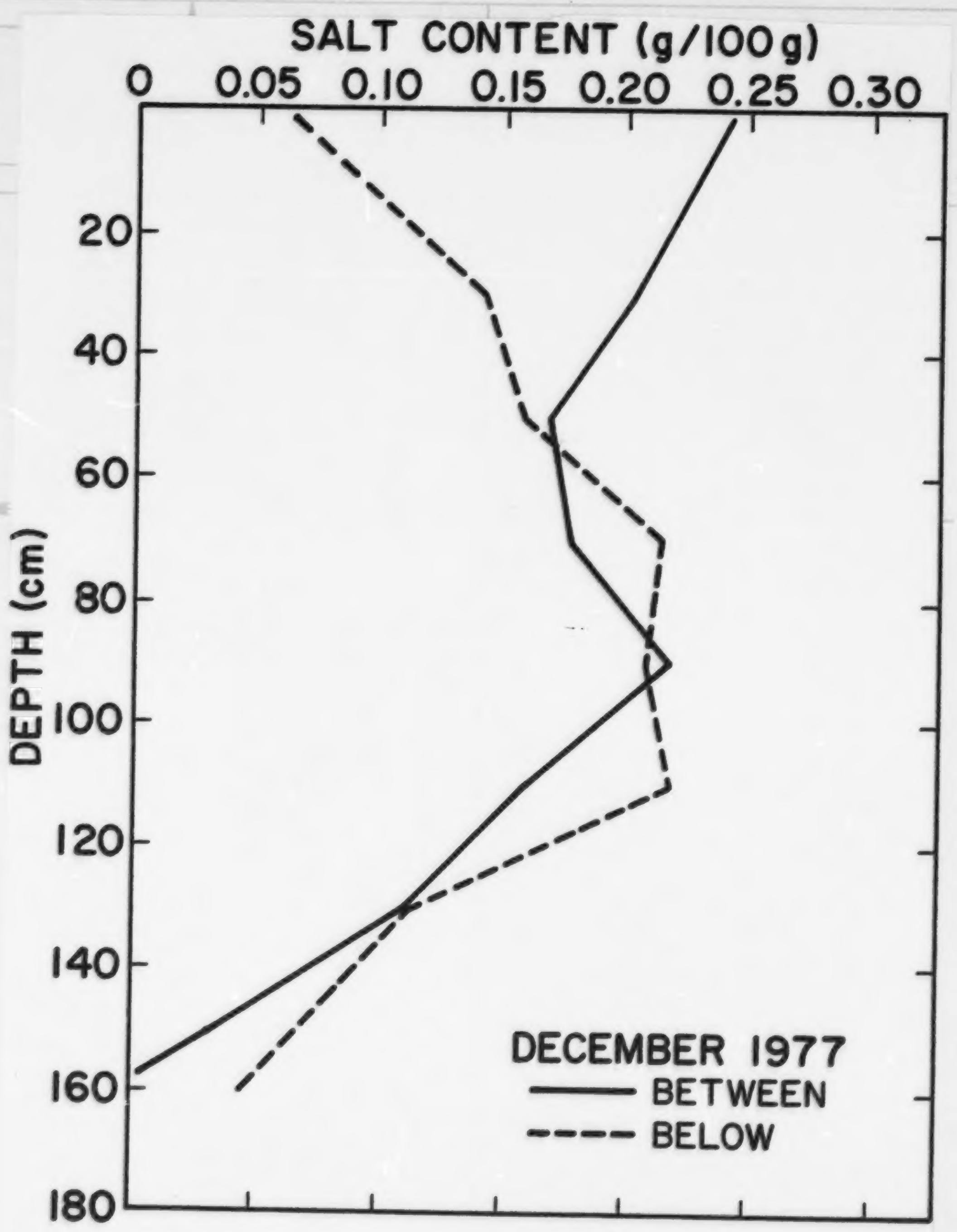

Figure 12. Salt distributions (g/100g soil) below and between trickle lines in December 1977.

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trickle lines near the soil surface than just below the trickle lines. Salts are moved away from the trickle lines, and tend to accumulate in the center. However, below 50 cm, differences in soil salinity as measured below and between the trickle lines tend to disappear.

Yield and Quality of Surface Irrigated Cotton for 1976

The average yields for each irrigation treatment are listed in Table 23. Yields from the B plots were considerably higher than yields from the A plots. The A plots, or "old" plots, had undergone irrigation treatments for four years. The B plots were on the area adjacent to the "old" plots which were planted with cotton for the first time in five years. The cotton in the A plots showed some yellowing, perhaps the result of a nitrogen deficiency due to enhanced leaching of the soil during previous years, or due to nitrogen losses caused by the less than favorable soil structure (lack of aeration) in many of the A plots.

The first crop year that irrigation treatments had a significant effect on yield was 1976. The 100 percent efficiency treatment resulted in a significantly higher yield for the A plots (LSD (.05) = 157), perhaps a result of less nutrient losses due to leaching from this treatment during previous years. Irrigating the B plots at three week intervals resulted in reduced

TABLE 23. EFFECTS OF IRRIGATION EFFICIENCY AND WATER DEPLETION ON COTTON YIELDS FROM THE SURFACE-IRRIGATED PLOTS (1976)

Irrigation Interval	Irrigation Efficiency Percent 80	90	100	Average Yield
	(kg/ha)			
A-plots				
1 week	1100	1099	1455	1218
2 weeks	1087	1305	1502	1298
3 weeks	1362	1338	1375	1358
Average	1183a*	1247a	1444b	1292
B-plots				
1 week	1581	1482	1551	1538a
2 weeks	1586	1642	1538	1587a
3 weeks	1446	1347	1338	1377b
Average	1538a	1490a	1475a	1501

* Yield means followed by the same letter are not significantly different at the five percent or less level of probability.

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yields (LSD (.01) = 129). This would indicate that when total water applied is nearly equal to consumptive use, more frequent irrigation will produce higher yields.

An analysis of variance on the cotton quality factors showed no significant effects except the 2.5 percent span values for the A plots and lint percent for the B plots. The 2.5 percent span value for the 100 percent efficiency treatment on the A plots was significantly higher (LSD (.05) = .036) than this value for the 90 percent efficiency treatment or the 80 percent efficiency treatment. Mean 2.5 percent span values for the 100, 90, and 80 percent efficiency treatments were 1.18, 1.13, and 1.15, respectively. The 100 percent efficiency treatment, then, resulted in larger yields and higher 2.5 percent span values. Lint percent for cotton from the B plots was significantly higher (LSD (.05) = 1.1) when the plots were irrigated at one week intervals as opposed to two or three week intervals. Lint percent values for the one, two, and three week frequency treatments on the B plots were 37.5, 36.3, and 35.8 percent, respectively. Extending the irrigation interval decreased yield and lint percent for the B plots, but not for the A plots.

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Yield and Quality of Surface-Irrigated Cotton for 1977

The average yields for each irrigation treatment are listed in Table 24.

TABLE 24. EFFECTS OF IRRIGATION EFFICIENCY AND WATER DEPLETION ON COTTON YIELDS FROM THE SURFACE-IRRIGATED PLOTS (1977)

Irrigation Interval	Irrigation Efficiency Percent			Average Yield
	80	90	100	
	(kg/ha)			
A-plots				
1 week	1173	635	357	772
2 weeks	1158	1064	727	983
3 weeks	1252	1110	723	1038
Average	1194a*	937a	612b	914
B-plots				
1 week	1444	1257	734	1145
2 weeks	1457	1097	1024	1193
3 weeks	1536	1287	1026	1283
Average	1479a	1214b	928c	1207

* Yield means followed by same letter are not significantly different at the five percent or less level of probability.

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In 1977, yields were significantly higher for the 80 percent irrigation efficiency treatment than for the 100 percent efficiency treatment on both the A plots (LSD (.05) = 267) and the B plots (LSD (.05) = 135).

The 1977 rainfall was below average, while air temperatures during the summer months were above those of 1976. However, the pan evaporation for the months of May, June, July, and August 1977 was 114.0 cm as opposed to 114.6 cm for the same period in 1976, indicating that the potential evapotranspiration may have been about the same in 1977 and 1976. The total amounts of irrigation and rain water were also about the same for 1976 and 1977. Yields from the 90 and 100 percent efficiency treatments may have been reduced as a result of lack of water. Since the amount of salinity in the 80 and 90 percent efficiency plots was not significantly different from the salinity in the 100 percent efficiency plots, salt content is not a probable cause for the yield differences between irrigation efficiency treatments in 1977.

An analysis of variance on the cotton quality factors showed an effect of depletion on micronaire and an effect of irrigation efficiency on strength for the A plots in 1977. Mean micronaire values for the one, two, and three week irrigation intervals were 3.61, 3.82, and 4.06, respectively (LSD (.05) = .30). Fiber strength was highest for the 100 percent efficiency treatment and lowest for the 90 percent efficiency treatment. Mean values of fiber strength for the 80, 90, and 100 percent efficiency treatments were 21.9, 21.8, and 23.4, respectively (LSD (.05) = 1.04). No significant effects of treatment on cotton quality were observed for the B plots in 1977.

Yield and Quality of Surface-Irrigated Cotton for the Combined Years 1972-1977

Table 25 presents the yield data for the years 1972, 1973, 1974, 1976 and 1977 (see Wierenga (1977) for cotton data for 1972-1974). For 1976 and 1977, only the data from the A plots are given in order to compare yields from the same plot area in all years. The yields averaged over the years 1972-1977 are also given for the various treatments.

An analysis of variance on the yield data for the combined years 1972-1977 showed no significant effects due to depletion or efficiency at the 5 percent confidence level. However, there was significant interaction (5% <P (f) <10%) between depletion and efficiency effects. This is illustrated in Figure 13. While yields from the 25% (1 week interval), and 75% (3 week interval) depletion treatments decreased sharply with increased irrigation efficiency, yields from the 50% depletion treatments were affected little by efficiency treatments. The general trends shown in Figure 13 are similar to those shown before in 1972, 1973, and 1974 (Wierenga, 1977). For the experimental soil, infrequent irrigation combined with some leaching will provide the highest yields. When water is scarce it appears advantageous to irrigate more frequently (every two weeks) but, irrigating too frequently (once a week) may greatly reduce yields.

The effects of irrigation treatments on cotton quality factors over the years 1972-1977 are summarized in Table 26. A summary of the analysis of variance on the yield and quality data is presented in Table 27. For all

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TABLE 25. EFFECTS OF IRRIGATION EFFICIENCY AND WATER DEPLETION ON COTTON YIELDS FROM THE SURFACE-IRRIGATED PLOTS (1972, 1973, 1974, 1976*, 1977*)

Water Depletion Percent or Irrigation Interval	Irrigation Efficiency Percent 80	90	100	Average Yield
	(kg/ha)			
1972				
25%	930	753	803	829
50%	842	962	1001	935
75%	1067	977	889	978
Average	946	897	898	914
1973				
25%	1487	1270	1177	1312
50%	1388	1407	1392	1395
75%	1338	1283	1306	1309
Average	1404	1320	1292	1339
1974				
25%	1054	1018	930	1001
50%	1143	1132	1029	1102
75%	1084	942	929	984
Average	1094	1031	963	1029
1976*				
1-week	1100	1099	1455	1218
2-week	1087	1306	1502	1298
3-week	1362	1338	1375	1358
Average	1183	1247	1444	1292
1977*				
1-week	1173	635	359	722
2-week	1158	1065	727	983
3-week	1252	1109	753	1038
Average	1194	937	612	914
1972, 1973, 1974, 1976*, 1977*				
25%, 1-week	1149	955	945	1016
50%, 2-week	1124	1174	1130	1142
75%, 3-week	1220	1130	1050	1134
Average	1164	1087	1042	1098

* For 1976 and 1977 yield data from the A-plots are presented to show the effect of treatments on yield from the same plot area.

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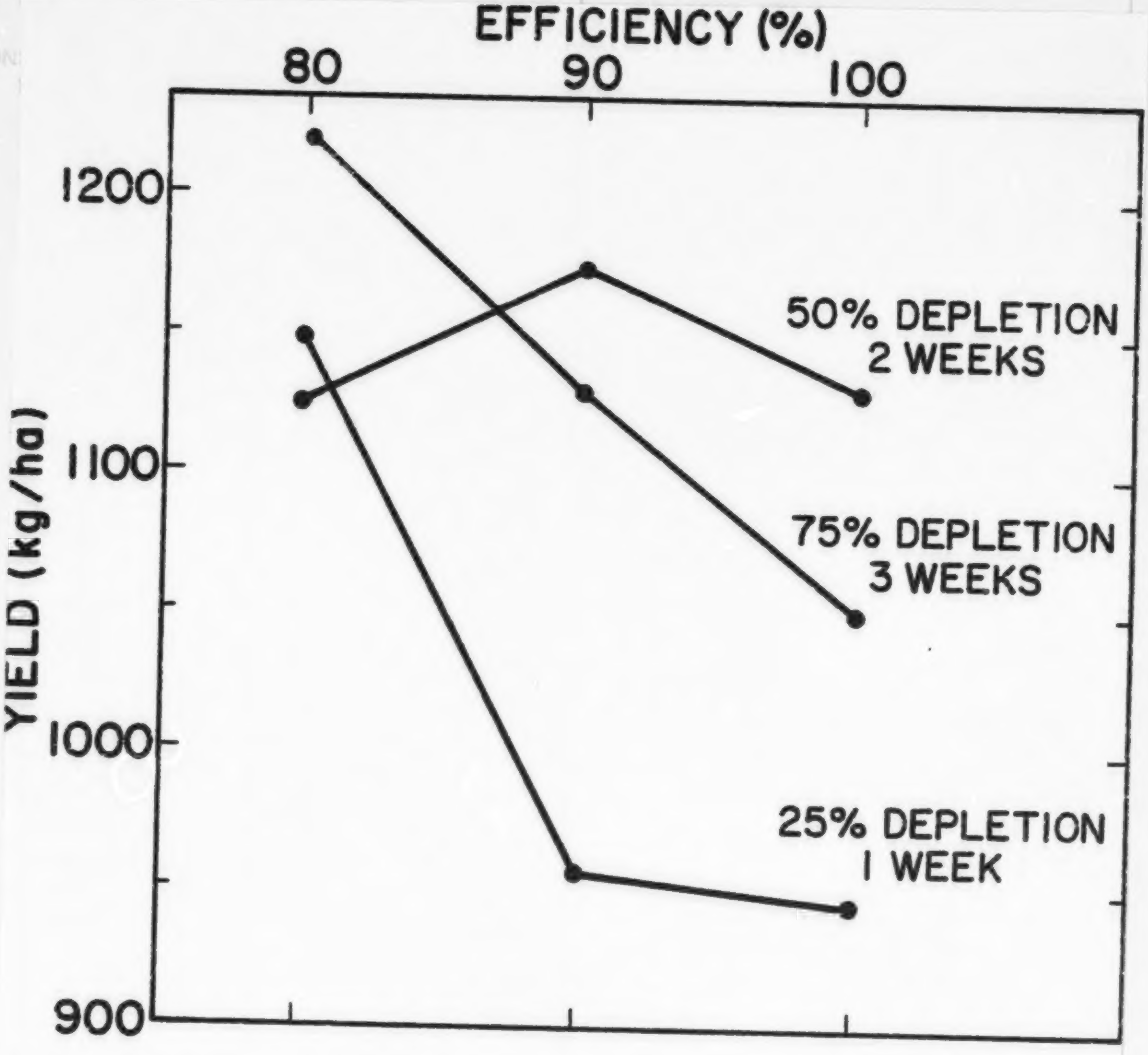

Figure 13. General trends in cotton yield as affected by depletion (irrigation interval) and efficiency (averages of 1972, 1973, 1974, 1976 and 1977).

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TABLE 26. EFFECTS OF IRRIGATION EFFICIENCY AND WATER DEPLETION ON COTTON QUALITY FROM THE SURFACE-IRRIGATED PLOTS (1972-1977*, COMBINED)

Water Depletion Percent And Irrigation Interval	Unit	Irrigation Efficiency Percent 80	90	100	Average
25%, 1 week	% Lint	38.8	37.9	37.3	38.0
50%, 2 weeks	% Lint	38.6	38.0	37.0	37.9
75%, 3 weeks	% Lint	37.5	37.6	38.1	37.8
Average	% Lint	38.3	37.8	37.5	37.9
25%, 1 week	2.5% Span	1.16	1.16	1.17	1.16
50%, 2 weeks	2.5% Span	1.17	1.18	1.17	1.17
75%, 3 weeks	2.5% Span	1.20	1.17	1.17	1.18
Average	2.5% Span	1.18	1.17	1.17	1.17
25%, 1 week	Uniformity Ratio	47.0	46.5	45.4	46.3
50%, 2 weeks	Uniformity Ratio	46.5	46.3	46.2	46.3
75%, 3 weeks	Uniformity Ratio	46.7	46.3	46.5	46.5
Average	Uniformity Ratio	46.7	46.3	46.0	46.4
25%, 1 week	Micronaire	3.77	3.60	3.54	3.64
50%, 2 weeks	Micronaire	3.79	3.76	3.80	3.78
75%, 3 weeks	Micronaire	3.83	4.01	3.84	3.89
Average	Micronaire	3.79	3.79	3.73	3.77
25%, 1 week	Strength	22.5	22.5	22.9	22.6
50%, 2 weeks	Strength	22.1	22.7	23.1	22.6
75%, 3 weeks	Strength	23.1	22.9	23.3	23.1
Average	Strength	22.5	22.7	23.1	22.8
25%, 1 week	Elongation	6.63	6.68	6.31	6.54
50%, 2 weeks	Elongation	6.36	6.77	6.77	6.63
75%, 3 weeks	Elongation	6.87	6.70	6.64	6.74
Average	Elongation	6.62	6.71	6.58	6.64

* no crop grown in 1975.

quality factors, except micronaire, there were highly significant differences between years, indicating that the weather during a particular crop year has an important effect on cotton quality.

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TABLE 27. ANALYSIS OF VARIANCE ON COTTON YIELD AND QUALITY FACTORS FOR THE SURFACE-IRRIGATED PLOTS FOR THE COMBINED YEARS 1972, 1973, 1974, 1976 and 1977

Source of Variation	Yield	Lint Percent	2.5% Span	Unif. Ratio	Micronaire	Strength	Elongation
Years	**	**	**	**	ns	**	**
Efficiency	**	*	ns	ns	ns	**	ns
Depletion	**	ns	*	ns	**	*	ns
Efficiency x Depletion	*'	*	*	ns	ns	ns	ns
Years x Efficiency	**	ns	ns	ns	ns	*	ns
Years x Depletion	ns	ns	ns	ns	ns	ns	ns
Years x Depletion x Efficiency	ns	ns	ns	ns	ns	ns	ns

** and * denote significant differences at the 5 percent and 1 percent levels of significance, respectively.

*' 5% < P(f) < 10%

The two most important crop quality parameters are lint percent and 2.5 percent span. Irrigation efficiency had a significant effect on lint percent, but not on 2.5 percent span, while depletion had a significant effect on 2.5 percent span, but not on lint percent. For both factors, however, there was a significant efficiency x depletion interaction. It is interesting to note that micronaire did not differ significantly from year to year, but was very significantly affected by percent depletion. Apparently, frequent irrigation does favor high micronaire values. Fiber strength also was affected by efficiency and depletion treatments, tending to be highest for the 100 percent efficiency treatment and the three week irrigation interval. There was in addition, however, a years x efficiency interaction with fiber strength. In general, frequent, low efficiency irrigation apparently reduced fiber strength of cotton.

Yield and Quality of Trickle Irrigated Cotton

An analysis of variance was performed on the cotton yield and quality data from the trickle plots for the years 1976 and 1977, and for 1976 and 1977 combined. There were no significant differences in yield or quality between treatments in 1976 and in 1977, nor between 1976 and 1977 combined.

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The trickle-irrigation treatments consisted of: a. Irrigation when the soil water tension 20 cm below the trickle line reached 0.2 bars; b. Irrigation at the same time as treatment a. but with 0.7 of the amount of water applied to treatment a. The difference between the amounts of water applied to the two treatments was apparently not enough to have a significant effect on cotton yield or quality.

Effects on the amount of soil-water on yield and quality of cotton from the trickle-irrigated plots for the years 1972-1977, and for these years combined, are shown in Table 28. Note that from 1972 to 1974 the "dry" treatment consisted of irrigating when the soil-water tension 20 cm below the trickle line reached 0.6 bars. Since it was difficult to keep the tensiometers in operating condition in the 0.6 bar treatment, this treatment was changed to one in which 0.7 x the amount of water for the 0.2 bar treatment was applied. A separate analysis of variance was made, therefore, for the years 1972-1974, but no significant effects were detected in yield or quality as a result of treatments. Table 29 presents the analysis of variance on cotton yield and quality factors for the combined years 1972-1977.

Except for the 2.5 percent span factor, there was a strong year effect on yield and quality. Water amount affected micronaire, but had no significant effect on yield or the other quality parameters.

It is of interest to compare the mean yield and quality data for the trickle-irrigated plots with those of the surface-irrigated plots (Table 30). The data show a 6 percent higher yield for the trickle-irrigated plots, but very little difference in cotton quality parameters.

Water Quality in Observation Wells and Irrigation Well

The electrical conductivities and chemical composition of the water samples from the five test wells and the irrigation well during 1972-1977 is presented in Wierenga, (1979). Yearly averages of the chemical analysis are given, also, in Table 31. Analyses averaged over the period April 20, 1972 to October 6, 1977 for the samples from the test wells (October 13, 1972 to October 5, 1977 for the irrigation well) are presented in Table 32.

Changes in the quality of the water in the test wells and irrigation well during the six years of this study are illustrated in Figure 14. Water in the deeper wells was of a better quality than the water in the shallow wells. The irrigation well, located about 100 m north of the test wells, had water of a quality intermediate between that of the test wells at 15.5 and 22.9 m.

The rather sharp increase in electrical conductivity in the test wells in 1974 may be the result of a leaching experiment conducted during the spring of that year. In that period, plot no. 4 (located 20 m west of the test wells) was irrigated at a constant rate of 2 cm/day (evaporation prevented) for 128 days. From January 11 until February 22, 1974, plot 4 was irrigated with water from the irrigation well which had a chloride concentration of 16.2 meq/liter. On March 30, leaching was continued with well water without calcium chloride added. During the experiment, the electrical

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TABLE 28. EFFECTS OF SOIL WATER ON YIELD AND QUALITY OF COTTON FROM THE TRICKLE-IRRIGATED PLOTS FOR 1972, 1973, 1974, 1976 AND 1977

Tension Bars	Yield (kg/ha)	Lint Percent (%)	2.5% Span	Unif. Ratio	Micronaire	Strength	Elongation
1972							
0.2	1254	36.3	1.21	44.6	3.52	22.7	7.20
0.6	1119	37.2	1.16	44.7	4.12	24.8	6.33
Average	1186	36.7	1.18	44.7	3.82	23.8	6.77
1973							
0.2	1244	37.7	1.16	44.0	3.23	24.0	5.90
0.6	1375	37.3	1.19	44.3	3.72	23.4	6.50
Average	1310	37.5	1.18	44.1	3.48	23.7	6.20
1974							
0.2	1065	36.6	1.20	45.9	3.30	20.7	6.33
0.6	1074	37.4	1.17	46.1	3.25	21.3	6.27
Average	1070	37.0	1.19	46.0	3.27	21.0	6.30
1976							
0.2	1302	38.8	1.18	45.6	3.73	23.4	6.43
.7x	1328	38.5	1.18	45.5	3.73	22.5	7.03
Average	1315	38.6	1.18	45.6	3.73	23.0	6.73
1977							
0.2	1097	40.1	1.20	47.9	3.73	22.6	7.20
.7x	775	39.6	1.17	48.0	4.23	23.5	7.20
Average	936	39.8	1.18	47.9	3.98	23.0	7.20
1972, 1973, 1974, 1976, 1977							
0.2	1192	37.9	1.19	45.6	3.50	22.7	6.61
0.6 and .7x	1134	38.0	1.17	45.7	3.81	23.1	6.67
Average	1163	37.9	1.18	45.7	3.66	22.9	6.64

conductivity of the well water was 1.16 mmhos/cm, whereas the electrical conductivity of the concentrated leaching water was 2.5 mmhos/cm (van de Pol, Wierenga and Nielsen, 1977).

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TABLE 29. ANALYSIS OF VARIANCE ON THE COTTON YIELD AND QUALITY FACTORS FOR THE TRICKLE-IRRIGATED PLOTS FOR THE COMBINED YEARS 1972, 1973, 1974, 1976 AND 1977

Source of Variation	Yield	Lint Percent	2.5% Span	Unif. Ratio	Micro-naire	Strength	Elong-ation
Years	**	**	ns	**	**	*	**
Tension	ns	ns	ns	ns	*	ns	ns
Years x Tension	*	ns	ns	ns	ns	ns	ns

** and * denote significant differences at the 5 percent and 1 percent levels of significance, respectively.

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TABLE 30. MEAN YIELD AND QUALITY DATA (AVERAGED FOR ALL YEARS AND TREATMENTS) FOR THE SURFACE- AND TRICKLE-IRRIGATED PLOTS

Irrigation Method	Yield (kg/ha)	Lint Percent (%)	2.5% Span	Unit. Ratio	Micro-naire	Strength	Elong-ation
Surface Irr.	1098	37.9	1.17	46.4	3.8	22.8	6.6
Trickle Irr.	1163	37.9	1.18	45.7	3.7	22.9	6.6

Figure 14 shows that the increase in electrical conductivity of the water in the shallow wells corresponds with the leaching of plot no. 4. As expected, there is a decrease in peak concentration and a flattening of the concentration versus time curve with increasing depth below the soil surface. The quality of the water in the irrigation well (located about 100 m north of plot 4) was not affected by the leaching experiment.

Quantity and Quality of Water in the Del Rio Drain

Quantity of Drain Flow--

Flow rates at the Del Rio Drain sampling stations A and B are plotted for the years 1975-1977 (Figures 15-17). There is a gradual increase in drain flow during the irrigation season, with the maximum flow occurring during August or the eary part of September. After September, drain flow

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TABLE 31. MEAN YEARLY CHEMICAL COMPOSITION (meq/ℓ, except NO_3^- in ppm) OF WATER SAMPLES FROM TEST WELLS AND IRRIGATION WELL FOR 1972-1977

Well	Year	Depth	$ECx10^3$	pH	Total Cations	Total Anions	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4	NO_3
											MEQ/L				
1	1972	22.9	1.14	7.6	11.4	11.7	5.1	1.6	4.5	0.2	2.7	0.3	3.8	4.9	0.1
1	1973	22.9	1.07	7.4	11.1	11.3	5.3	1.5	4.1	0.2	2.7	0.2	3.8	4.5	1.5
1	1974	22.9	1.05	8.0	11.5	11.4	6.1	1.7	3.6	0.2	2.9	0.1	3.6	4.8	0.2
1	1975	22.9	1.03	8.1	11.4	11.3	5.5	1.6	4.2	0.2	2.7	0.0	3.8	4.7	0.4
1	1976	22.9	0.94	8.2	10.8	10.6	5.5	1.7	3.5	0.1	2.6	0.3	3.5	4.2	0.7
1	1977	22.9	1.09	8.1	11.5	11.7	5.7	1.6	4.0	0.1	2.6	0.2	4.0	4.9	0.1
Mean	1972-1977		1.05	7.9	11.3	11.3	5.5	1.6	4.0	0.2	2.7	0.2	3.8	4.7	0.5
2	1972	15.5	1.51	7.5	16.5	16.7	8.3	2.2	5.8	0.3	3.5	0.1	6.1	7.1	--
2	1973	15.5	1.45	7.4	16.0	16.2	7.9	2.1	5.8	0.2	3.3	0.4	5.9	6.6	2.0
2	1974	15.5	1.37	8.1	15.0	15.3	6.8	2.0	6.0	0.2	2.8	0.1	5.9	6.6	0.3
2	1975	15.5	1.17	8.0	13.3	13.2	6.0	1.8	5.4	0.2	2.4	0.1	5.4	5.4	0.2
2	1976	15.5	1.14	8.1	12.7	12.8	5.3	1.8	5.4	0.2	2.3	0.1	5.0	5.3	0.5
2	1977	15.5	1.39	8.0	15.1	15.3	7.4	1.9	5.5	0.2	2.8	0.2	5.9	6.5	0.0
Mean	1972-1977		1.34	7.9	14.8	15.1	7.0	2.0	5.7	0.2	2.9	0.2	5.7	6.3	0.6
3	1972	11.0	1.60	7.5	17.0	17.2	8.1	2.4	6.3	0.2	3.5	0.0	6.4	7.4	--
3	1973	11.0	1.49	7.3	16.3	16.4	7.5	2.3	6.3	0.2	3.2	0.3	6.1	6.8	2.0
3	1974	11.0	1.74	8.0	19.4	19.1	9.3	2.8	7.1	0.3	4.5	0.1	6.0	8.6	0.3
3	1975	11.0	1.35	8.0	15.6	15.2	7.1	2.1	6.2	0.2	2.8	0.0	6.0	6.4	0.2
3	1976	11.0	1.15	8.3	13.0	13.1	5.0	1.7	6.1	0.2	2.3	0.4	5.1	5.3	0.9
3	1977	11.0	1.35	8.1	14.4	14.8	6.5	1.8	6.0	0.2	2.8	0.3	5.8	6.0	0.1
Mean	1972-1977		1.45	7.9	16.0	16.0	7.3	2.2	6.3	0.2	3.2	0.2	5.9	6.8	0.7

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TABLE 31. (Continued)

Well	Year	Depth	ECx10^3	pH	Total Cations	Total Anions	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4	NO_3
		(m)					MEQ/L								
4	1972	8.2	1.46	7.5	15.2	15.4	6.9	2.3	5.6	0.2	3.1	0.0	5.7	6.6	--
4	1973	8.2	1.53	7.3	17.0	16.5	7.8	2.6	6.3	0.3	3.1	0.2	6.8	6.4	1.7
4	1974	8.2	1.89	8.0	20.8	21.1	9.3	3.2	8.1	0.3	4.7	0.0	6.5	9.9	0.6
4	1975	8.2	1.30	8.1	15.0	14.5	5.1	1.7	8.0	0.2	2.7	0.1	6.0	5.7	0.2
4	1976	8.2	1.24	8.1	13.9	13.8	5.1	2.0	6.6	0.2	2.8	0.1	5.3	5.6	0.7
4	1977	8.2	1.40	7.9	15.1	15.5	6.6	2.1	6.2	0.2	2.7	0.1	6.7	6.0	0.0
Mean	1972-1977		1.47	7.8	16.2	16.1	6.8	2.3	6.8	0.2	3.2	0.1	6.2	6.7	0.6
5	1972	5.8	1.50	7.3	15.6	16.2	6.7	2.9	5.7	0.3	3.3	0.2	6.0	6.7	--
5	1973	5.8	1.40	7.4	15.5	14.9	6.8	2.6	5.8	0.3	3.2	0.3	5.9	5.4	1.2
5	1974	5.8	2.00	7.9	22.3	22.3	10.5	3.9	7.6	0.3	5.4	0.0	6.1	10.9	0.8
5	1975	5.8	1.44	8.0	16.3	16.1	6.0	2.3	7.7	0.3	3.1	0.0	6.1	6.9	0.3
5	1976	5.8	1.28	8.1	14.4	14.5	4.6	2.0	7.5	0.3	2.7	0.2	5.9	5.7	0.5
5	1977	5.8	1.36	7.9	14.5	14.6	5.7	2.1	6.5	0.2	2.4	0.1	6.6	5.5	0.1
Mean	1972-1977		1.50	7.8	16.4	15.1	6.7	2.6	6.8	0.3	3.4	0.1	6.1	6.9	0.6
Irr	1972	26.0	1.35	7.7	12.9	12.7	5.4	1.9	5.3	0.2	2.8	0.4	4.0	5.5	--
Irr	1973	26.0	1.28	7.4	13.3	14.0	5.8	1.8	5.5	0.2	2.7	0.2	5.0	6.1	1.7
Irr	1974	26.0	1.16	7.9	13.2	12.9	5.9	1.6	5.5	0.2	2.4	0.1	5.3	5.2	0.4
Irr	1975	26.0	1.16	8.0	13.0	12.7	5.7	1.6	5.5	0.2	2.6	0.0	4.7	5.4	0.3
Irr	1976	26.0	1.18	8.2	13.1	13.3	5.4	1.8	5.7	0.2	2.9	0.2	4.4	5.8	0.5
Irr	1977	26.0	1.28	8.0	13.8	13.9	6.4	1.7	5.5	0.2	2.8	0.0	5.2	5.8	0.5
Mean	1972-1977		1.23	7.9	13.2	13.2	5.8	1.7	5.5	0.2	2.7	0.2	4.8	5.6	0.7

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TABLE 32. MEAN CHEMICAL COMPOSITION (meq/ℓ, except NO_3^- in ppm) OF WATER SAMPLES FROM TEST WELLS AND IRRIGATION WELL FOR 1972-1977

Well Number	Depth	ECx10^3	pH	Total Cations	Total Anions	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4	NO_3
	(m)					- - - - - - - - - - - - meq/l - - - - - - - - - - -								(ppm)
1	22.9	1.05	7.9	11.3	11.3	5.5	1.6	4.0	0.2	2.7	0.2	3.8	4.7	0.5
2	15.5	1.34	7.9	14.8	15.1	7.0	2.0	5.7	0.2	2.9	0.2	5.7	6.3	0.6
3	11.0	1.45	7.9	16.0	16.0	7.3	2.2	6.3	0.2	3.2	0.2	5.9	6.8	0.7
4	8.2	1.47	7.8	16.2	16.1	6.8	2.3	6.8	0.2	3.2	0.1	6.2	6.7	0.6
5	5.8	1.50	7.8	16.4	15.1	6.7	2.6	6.8	0.3	3.4	0.1	6.1	6.9	0.6
Irrig. Well	26.0	1.23	7.9	13.2	13.2	5.8	1.7	5.5	0.2	2.7	0.2	4.8	5.6	0.7

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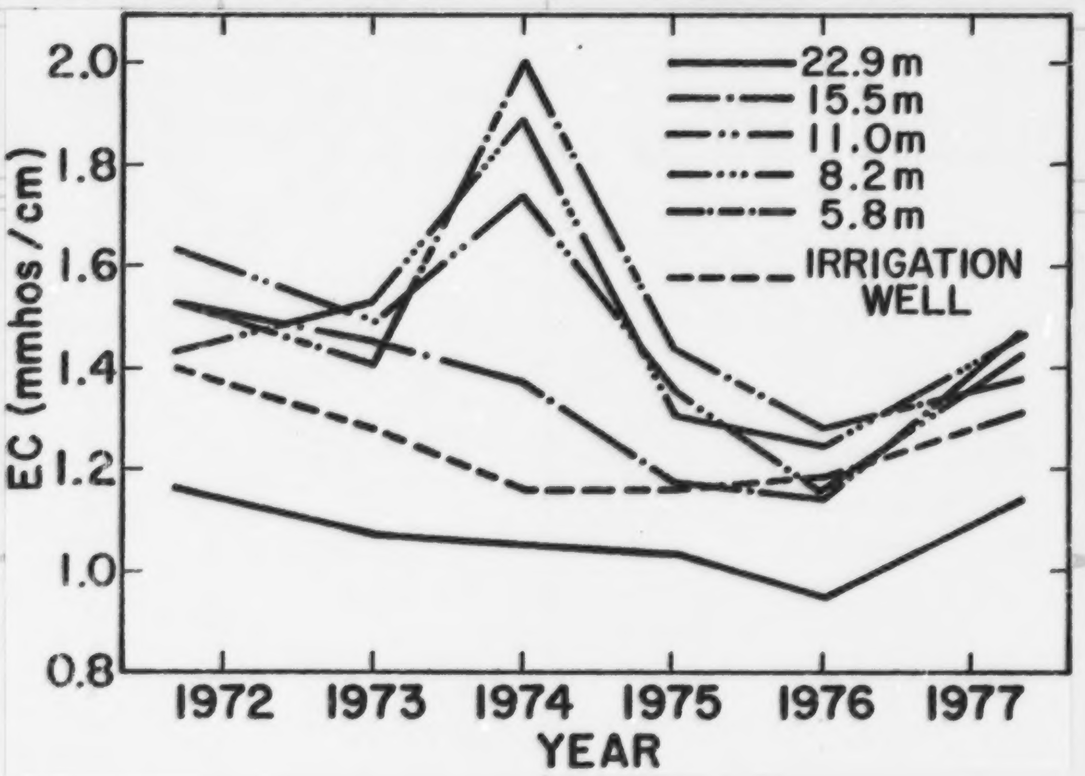

Figure 14. Mean annual electrical conductivity (mmhos/cm) of water in observation wells and irrigation well.

gradually levels off, and approximates the drain flow at the beginning of the irrigation season. The flow patterns shown in Figures 16-18 are very similar to those measured at sites A and B during the years 1972-1974 (Wierenga, 1977). There are, however, fairly large fluctuations in flow from one year to another which are largely a result of the varying amounts of surface water allotted by the Elephant Butte Irrigation district (see Table 33).

The surface water allocations for the years 1972 to 1977 are listed in the last column of Table 33. The years 1972 and 1977 were dry years, resulting in small water allocations, and reduced drain flow. Flow in 1973 was less than in the three following years, possible due to the heavy pumping for irrigation water and lowered water tables in 1972.

The increase in flow between Del Rio Drain sampling sites A and B, (located 4.5 km apart) fluctuated from one year to another and was lowest in 1977 when the surface water was limited to 38.1 cm (Table 33). The average increase in drain flow for the six years of study was 0.162 cubic meters per second, equivalent to 0.36 cubic meters per second per kilometer of drain.

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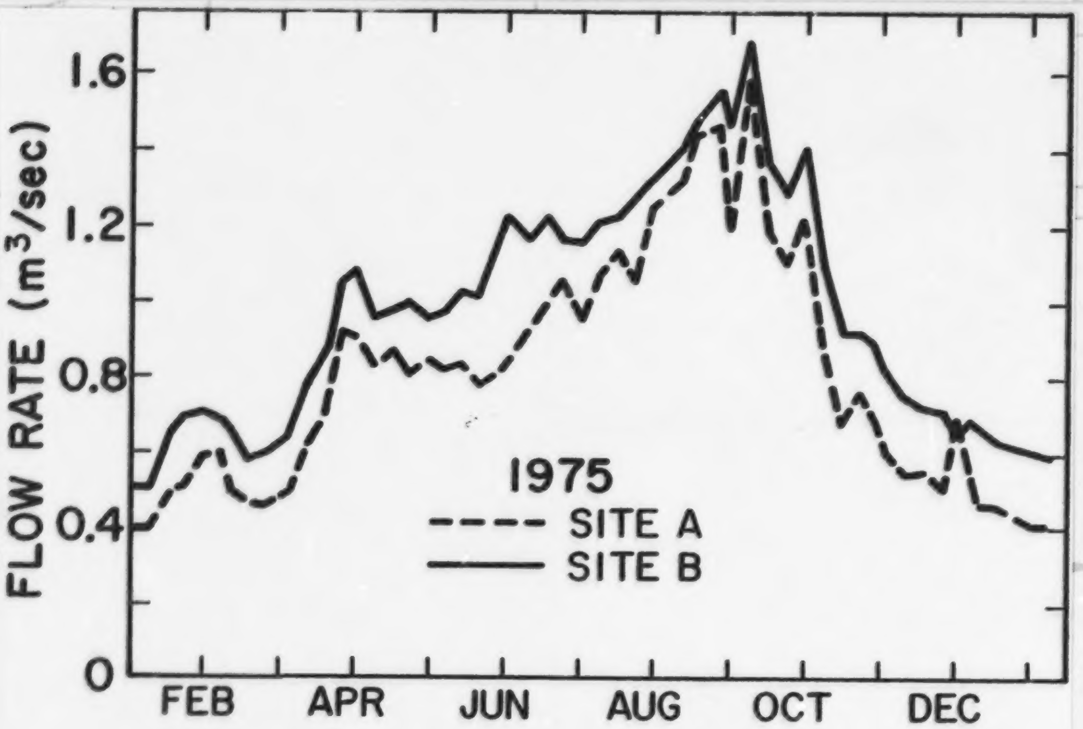

Figure 15. Flow at the Del Rio Drain sampling sites A and B in 1975.

TABLE 33. MEAN ANNUAL DRAIN FLOW (m^3 sec) AT DEL RIO DRAIN SITES A AND B AND IRRIGATION WATER ALLOTTED BY THE IRRIGATION DISTRICT FOR 1972 AND 1977

Year	Site A	Site B	Increase	Allotment
	(m^3/sec)	(m^3/sec)	(m^3/sec)	(cm)
1972	.418	.543	.125	20.3
1973	.670	.797	.127	91.4
1974	.809	1.007	.198	91.4
1975	.841	.990	.149	91.4
1976	.807	.963	.156	91.4
1977	.512	.567	.055	38.1

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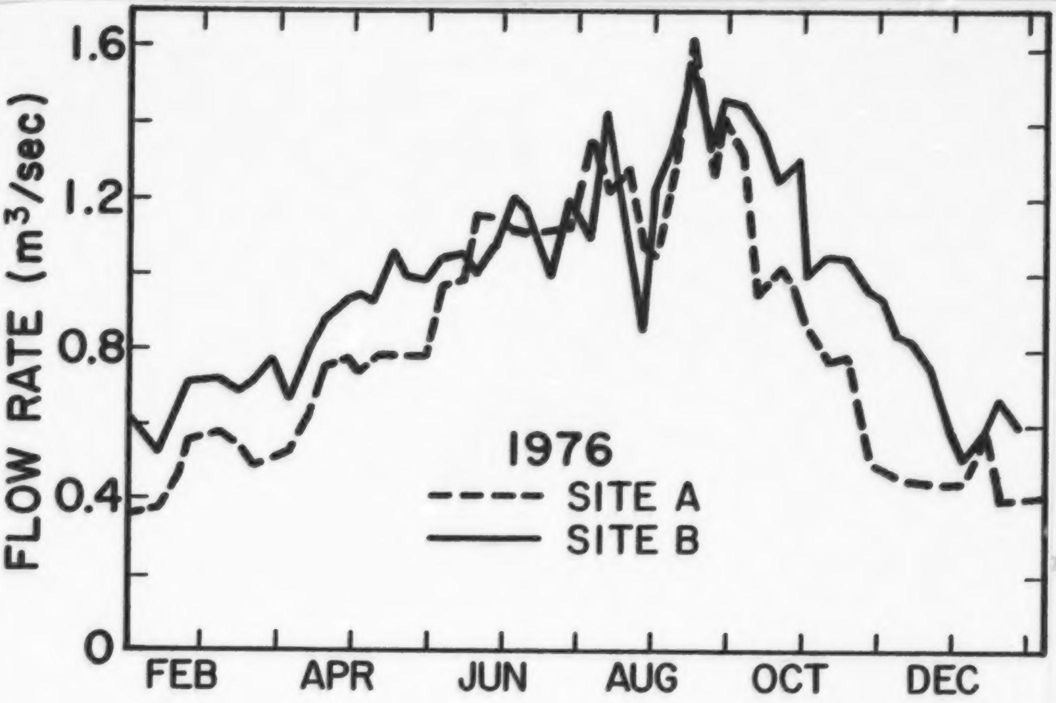

Figure 16. Flow at Del Rio Drain sampling sites A and B in 1976.

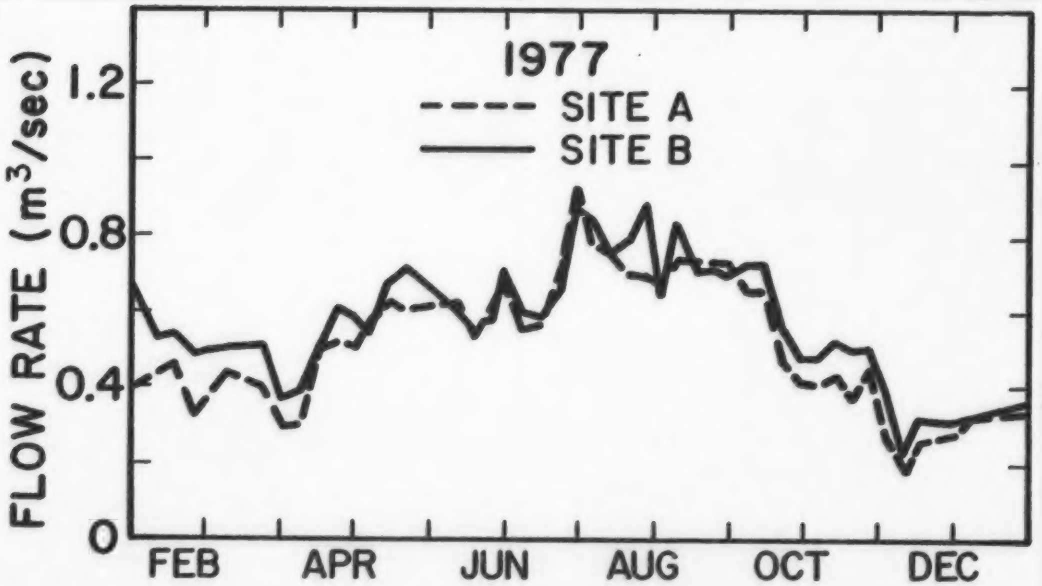

Figure 17. Flow at Del Rio Drain sampling sites A and B in 1977.

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Quality of Drain Flow--

The electrical conductivity of the water in the Del Rio Drain during 1975, 1976 and 1977 is plotted in Figures 18-20. As before (Wierenga, 1977), the conductivities decreased with increasing drain flow and were lowest in the summer months and highest in the winter months.

The weighted mean electrical conductivities of the Del Rio Drain sites A and B are presented in Table 34 for the years 1972-1977. The average increase in electrical conductivity between the two stations is presented in the last column of this table. For the combined years 1972 through 1977, the increase in EC was .047 mmhos/cm, equivalent to 0.01 mmhos/cm per km of drain length.

The weighted mean electrical conductivities and average flow rates measured at Del Rio site A are plotted in Figure 18. A strong inverse correlation between flow rate and the electrical conductivity is shown.

The arrow on the left hand scale of Figure 21 indicates the weighted mean electrical conductivity of the Del Rio Drain water samples taken between 1921 and 1936 above the outlet to the river approximately 18 km downstream from Station A (U.S.G.S., 1938). During those years, the salinity and flow rates were measured about four times per year, in contrast to the weekly measurements made during the present study. If it is assumed that the average yearly increase in salinity between sites A and B for the period 1972 to 1978, (0.01 mmhos/cm per km), was the same as between site A and the outlet into the river for the period 1921-1936, then the weighted mean EC at site A for the period 1921-1936 was 1.338 - 18 x 0.01 = 1.158 mmhos/cm. From 1972 to 1977 the weighted mean EC at site A was 1.255 mmhos/cm (see Table 34). On this basis, then there would appear to be a very small increase in salinity (0.07 mmhos/cm) between the periods 1921-1936 and 1972-1977. Though the assumption of a uniform increase of 0.01 mmhos/cm per km, with time and distance along the drain, may not be correct, the data show no indication of a substantial increase in salinity in the Del Rio Drain between 1921 and 1978.

The flow and water quality data taken at Del Rio Drain sites A and B were used to calculate the quality of the return flow entering the Del Rio Drain between sites A and B (see Wierenga, 1977). Values of the electrical conductivity (mmhos/cm) and chloride concentration (meq/ℓ) of the return flow water is reported by Wierenga, (1979).

The computed return flow EC and Cl concentrations are summarized in Table 35. The first column in Table 32 presents the computed electrical conductivity of the return flow (mmhos/cm), whle the second column presents the computed chloride concentration (meq/ℓ). The third and fourth columns present the average EC and chloride concentration for the five test wells. The data show agreement between the computed values and measured values, indicating that the five test wells fairly represent the quality of the water entering the drain between sites A and B.

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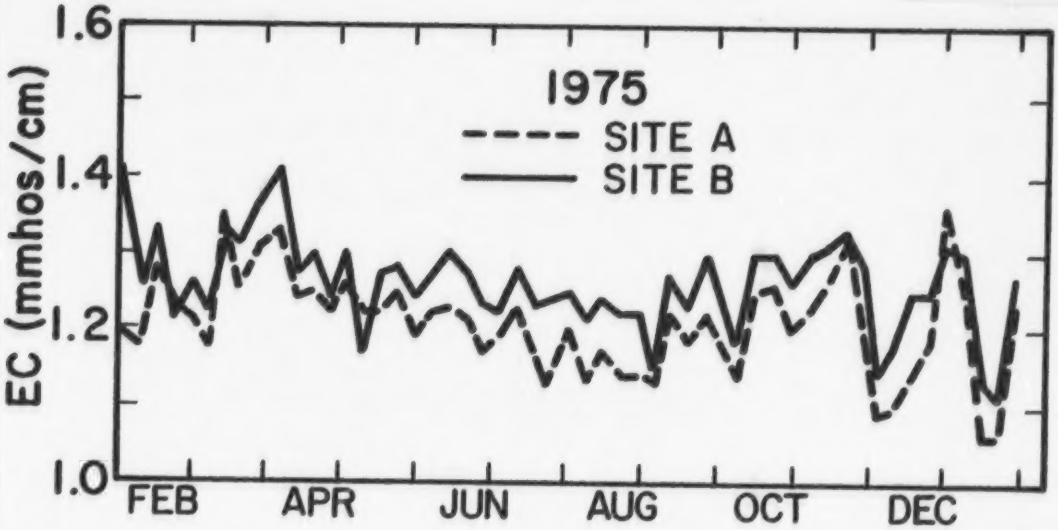

Figure 18. Electrical conductivities of water samples from Del Rio Drain sites A and B in 1975.

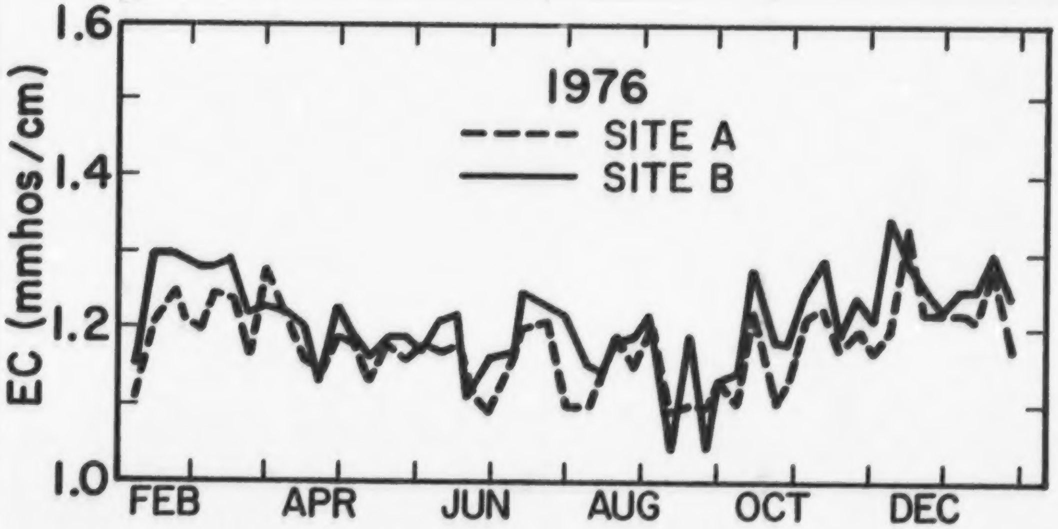

Figure 19. Electrical conductivities of water samples from Del Rio Drain sites A and B in 1976.

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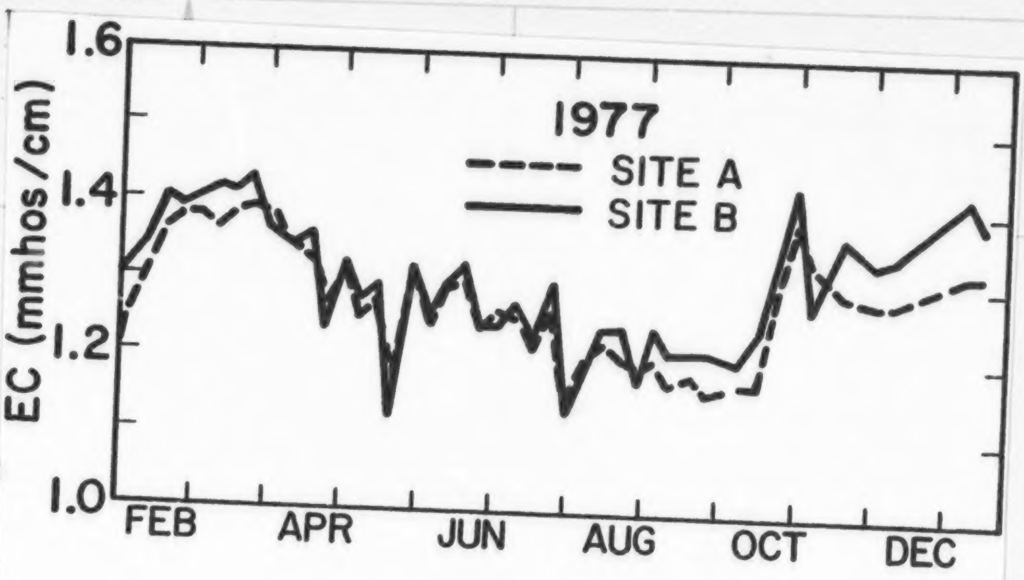

Figure 20. Electrical conductivities of water samples from Del Rio Drain sites A and B in 1977.

TABLE 34. WEIGHTED MEAN ANNUAL ELECTRICAL CONDUCTIVITY (mmhos/cm) OF WATER AT DEL RIO DRAIN SITES A AND B FOR THE YEARS 1972-1977

Year	Site A	Site B	B-A
		(mmhos/cm)	
1972	1.295	1.345	0.050
1973	1.222	1.284	0.062
1974	1.215	1.268	0.053
1975	1.203	1.255	0.052
1976	1.162	1.200	0.038
1977	1.250	1.277	0.027
Average	1.255	1.272	0.047

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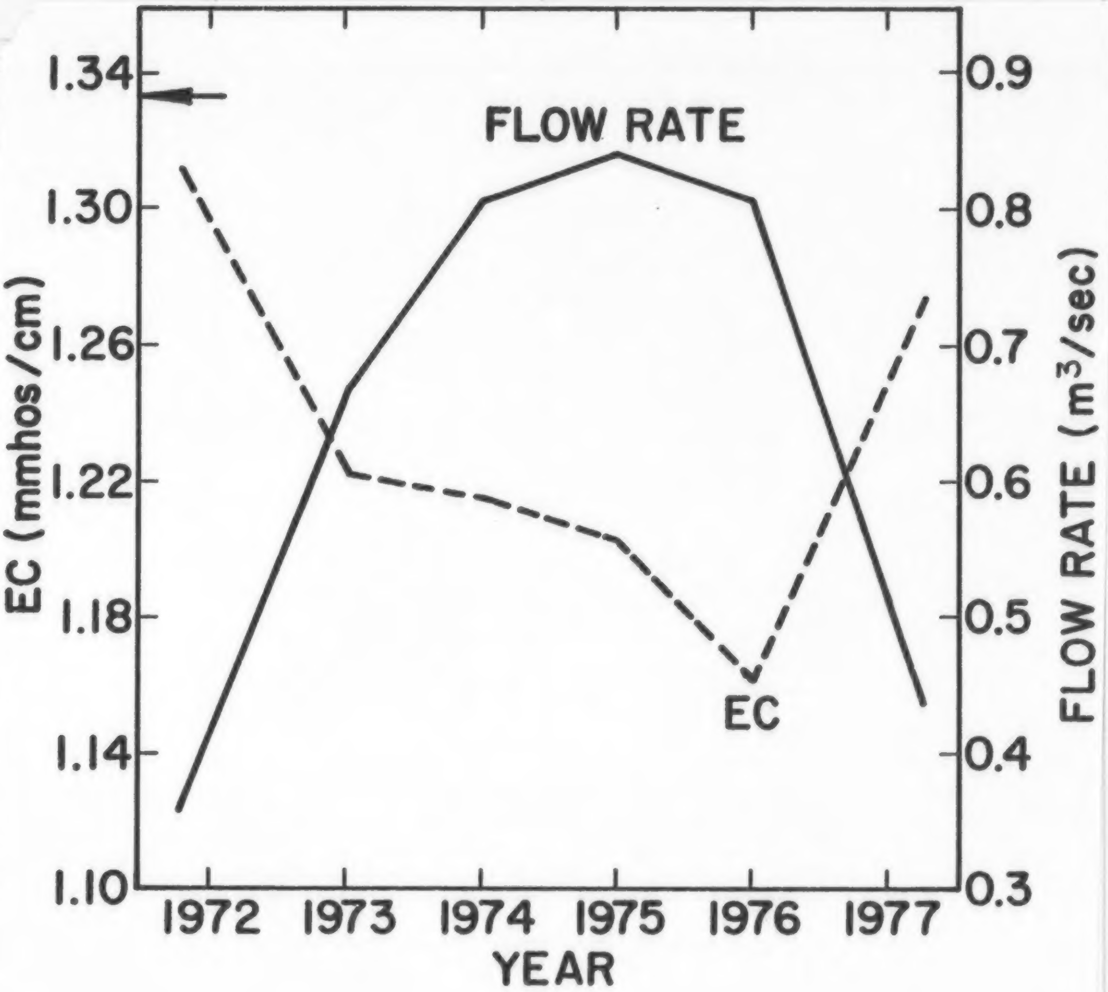

Figure 21. Weighted mean electrical conductivity and flow of water in the Del Rio Drain at site A for the years 1972-1977. The arrow indicates the weighted mean EC of Del Rio Drain water measured above the outlet to the Rio Grande River from 1921 to 1936.

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TABLE 35. COMPUTED EC (mmhos/cm) AND CL$^-$ (meq/ℓ) CONCENTRATION OF RETURN FLOW ENTERING THE DEL RIO DRAIN BETWEEN SITES A AND B. MEAN VALUES OF THE EC AND OF THE CL$^-$ CONCENTRATION OF THE TEST WELLS FROM 1972 to 1977 ARE ALSO PRESENTED

	----Return Flow-----		--Observation Wells-	
	EC	Cl	EC	Cl
1972	1.54	3.83	1.44	3.21
1973	1.53	3.94	1.39	3.11
1974	1.52	3.80	1.61	4.05
1975	1.25	3.54	1.26	2.75
1976	1.35	3.28	1.15	2.55
1977	1.55	3.23	1.32	2.66
Mean	1.46	3.62	1.36	3.06

No efforts were made to measure the quality of the water in the Rio Grande that is used for irrigating the land bordering the Del Rio Drain. However, data published by Wilcox (1968) show that the weighted mean electrical conductivity of the Rio Grande Water at Leasburg Dam between 1951 and 1963 was 0.89 mmhos/cm. Between April 1975 and September 1978 the U.S. Geological Survey collected 20 samples (6 or 7 per year) at Leasburg Dam, which is located approximately 20 miles north of site A. The arithmetic average electrical conductivity of the river water was 0.81 mmhos/cm. The ratio of the average electrical conductivity of irrigation water at Leasburg Dam (0.85 mmhos/cm) to the average electrical conductivity of the drainage return flow water (1.46 mmhos/cm) is 0.58. Assuming that the quality of the water used for irrigating the land bordering the Del Rio Drain between A and B is well represented by the river water quality as measured at Leasburg Dam, and assuming steady state conditions, this indicates that the ratio of the depths of drainage water to the depths of irrigation water is also 0.58. Thus, on the average, 58% of the irrigation water applied to the land bordering the Del Rio Drain between A and B is lost to the subsoil by deep percolation.

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SECTION 6

DEMONSTRATION FARM

INTRODUCTION

The general purpose of this portion of the study was to demonstrate the effect of alternate water management practices on the quantity and quality of irrigation drainage return flow, and to determine any detrimental effects these management practices would have on the soil salinity of the irrigated land. To accomplish this broad objective, a 182 hectare farm, located in central Mesilla Valley, was selected for the demonstration site (Figure 1). The specific objectives were:

1. To demonstrate the effects of salinity-control technologies, including canal lining, irrigation scheduling, and trickle irrigation, on the quantity and quality of return flow.

2. To measure the water flow and quality in the drain passing through the Demonstration Farm to determine the effect of water-management practice on irrigation return flow.

MATERIALS AND METHODS

The research on the Demonstration Farm consisted of three main areas:

1. Monitoring of applied water on the fields, and irrigation scheduling to determine irrigation efficiencies for these fields.

2. Installation and demonstration of a trickle-irrigation system, and monitoring of applied water on trickle-irrigated land to show the increased irrigation efficiency and decreased return flow.

3. Monitoring of the drain water flowing through the farm to determine if changes in irrigation practices could be detected by decreased flow rates and salinity levels in the drain.

The physical layout of the Demonstration Farm is presented in Figure 22. The farm contains an elaborate surface distribution system consisting of lined and unlined ditches and five wells to supplement surface-irrigation water. The drain runs through the center of the farm. The crops grown on the farm were wheat, tomatoes, cotton, lettuce, peppers, chile, grain sorghum, and alfalfa. There was also a producing pecan orchard. The cropping

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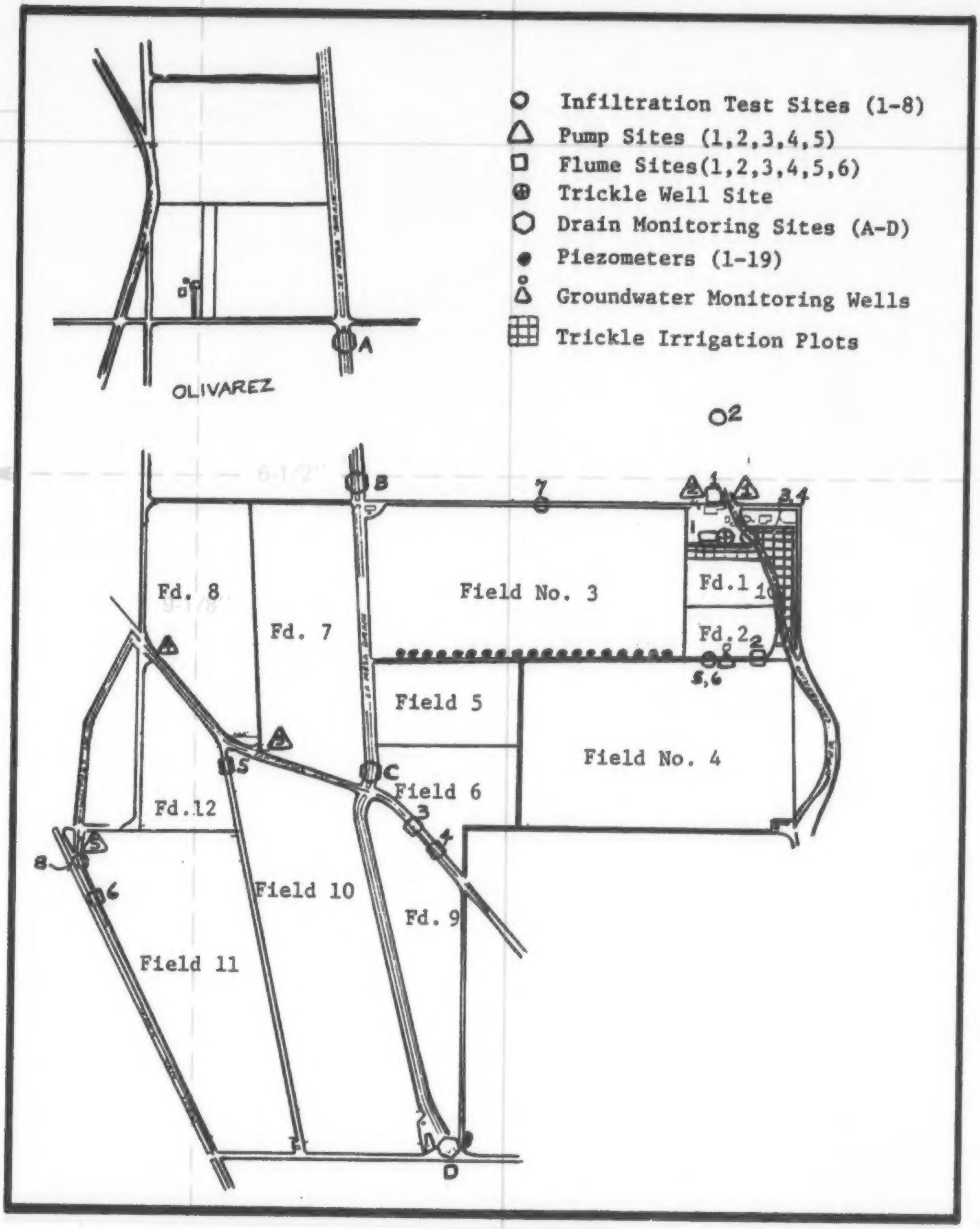
Infiltration Test Sites (1-8)
Pump Sites (1,2,3,4,5)
Flume Sites(1,2,3,4,5,6)
Trickle Well Site
Drain Monitoring Sites (A-D)
Piezometers (1-19)
Groundwater Monitoring Wells
Trickle Irrigation Plots
OLIVAREZ
A
B
C
D
Fd. 8
Fd. 7
Field No. 3
Fd.1
Fd.2
Field 5
Field No. 4
Field 6
Fd.12
Field 10
Fd. 9
Field 11
1
2
3
4
5
6
7
8
5,6
3,4

Figure 22. A diagram of the Demonstration Farm and the associated monitoring locations.

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pattern, which changed from year to year, is presented in Table 36 for the three years of the demonstration project.

Water-Measuring Equipment

To measure pumped water, 0.3 meter diameter McCrometer impeller-type flow meters were installed on all of the wells, Parshall flumes (throat width 43 cm and 22 cm) with Belfort and Stevens water-stage recorders were installed in all of the surface distribution canals so that a complete record of the applied water by field could be kept. Along with measuring the discharge from the wells, the natural gas consumption for each well on the Demonstration Farm was monitored. The irrigation pumps were tested for pump efficiency and overall efficiency. Two non-recording Taylor 28 cm rain gauges were installed at the Demonstration Farm to measure precipitation in the area.

Trickle-Irrigation Well

An irrigation well was developed to a depth of 75 meters to provide water for the trickle-irrigation system (Figure 23). An analysis of a water sample taken from the well is presented in Table 37, and a description of the material encountered from the well drilling is presented in Table 38.

Groundwater Monitoring

Nineteen piezometers were installed on a transect perpendicular to the drain as shown in Figure 22. They consisted of 1.2 cm diameter pipes driven into the ground below the water table. The pipes were slotted at the base to allow water entry. The depth to the water table was measured using a depth gauge and the depth corrected back to a datum elevation to account for the irregularities in the land surface.

Three wells, with 5 cm casings, were installed at 6, 10, and 15 meters to monitor the salinity of the groundwater at those depths (Figure 22). The wells were installed with a rotary drill rig and the information obtained from them at the beginning of the measurements should be carefully interpreted due to the contamination process of the drilling operation.

Drain Flow Monitoring

Bridges were built across the drain to allow easy and frequent measurements of the flow rate. Velocity measurements were made at 20 locations across the canal along with water-depth measurements. The area and subsequent flow rates for Sites B and D (Figure 22) were determined by the trapezoidal method.

Stilling wells were also installed in the La Mesa drain. Measurements, using Stevens water stage recorders, were determined at Sites B and D (Figure 22). Water samples were collected at Sites A through D and analyzed in the laboratory for salinity.

TABLE 36. HECTARES AND YIELDS PER HECTARE BY CROP FOR THE DEMONSTRATION FARM, 1975, 1976 and 1977

	Hectares			Yield			
	1975	1976	1977	Units	1975	1976	1977
Alfalfa	28.1	28.1	44.6	mt/ha	13.4	15.7	12.3
Chile	50.3	3.7	2.4				
Green				mt/ha	17.5	17.5	
Red				kg/ha	336	483	
Cotton	41.5	33.7	60.9				
Lint				kg/ha	443	538	841
Seed				kg/ha	740	900	1,400
Grain Sorghum	0	5.7	0	kg/ha		NA	
Lettuce	0	(20.2)*	(13.8)*	ctn/ha		1,236	0
Wheat	5.6	45.6	0	kg/ha	3,923	4,708	
Tomatoes	29.9	38.6	65.6	mt/ha	29.1	38.6	17.9
Pecans	1.3	1.3	1.3	kg/ha	388	448	1,214
Floral Gem Chile	8.0	8.1	3.2	kg/ha	NA	NA	NA
Cayenne Pepper	16.5	16.3	0.0	kg/ha	4,483	2,690	
Miscellaneous Vegetables	0.0	0.1	3.2				
Total	181.2	181.2	181.2				

* Double cropped

NA Not Available

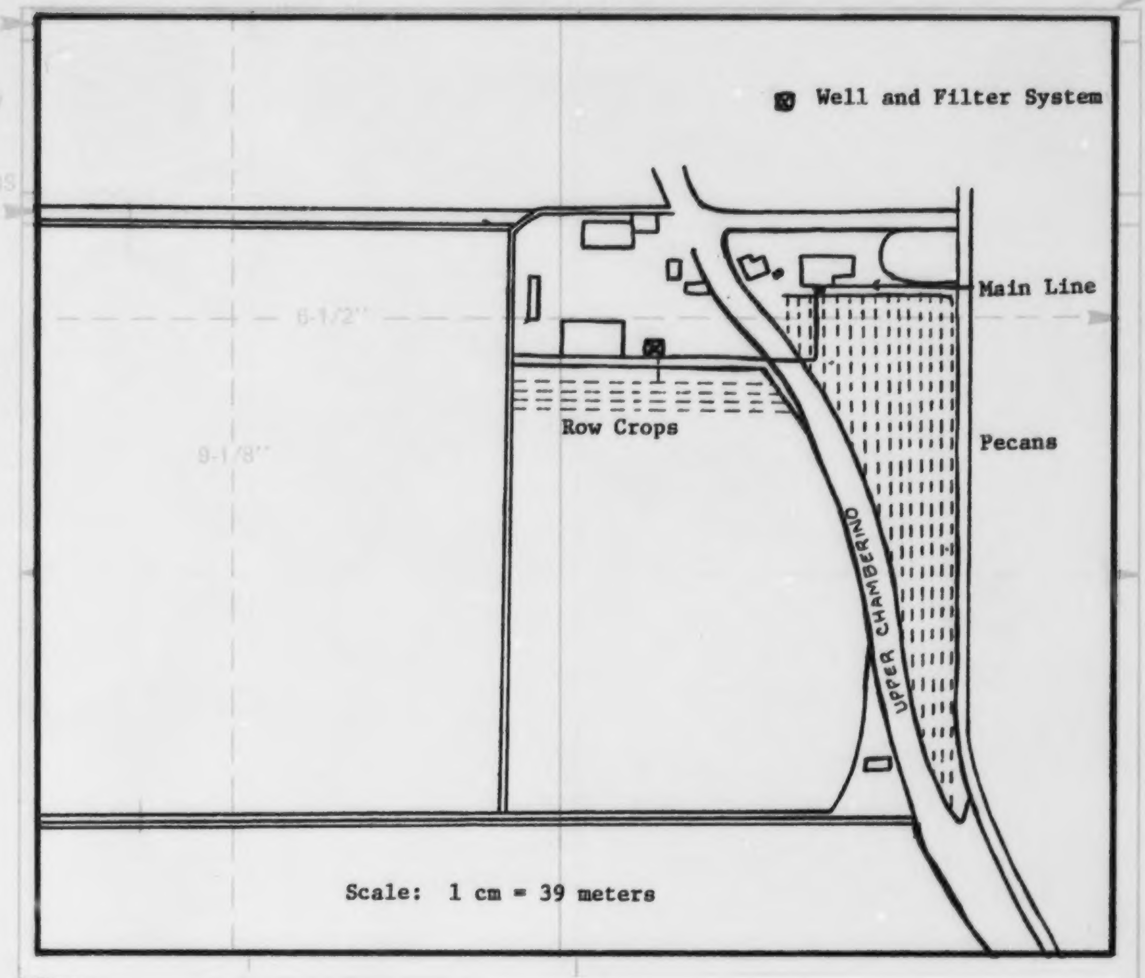

Figure 23. A schematic of the trickle irrigation system to irrigate pecans, tomatoes, and peppers at the Demonstration Farm

Irrigation Scheduling

Irrigation scheduling was furnished the Demonstration Farm through a contract with Agricultural Technology Incorporated, a commercial company providing irrigation scheduling for local farmers. The irrigation scheduling service was based on a climatological computer model to determine projected transpiration rates. Knowledge about the water-holding capacity and rooting depths of the crops, along with transpiration rates (Jensen, 1975), was used to determine the next irrigation date. The climate information used in the model came from a climatological station maintained at the New Mexico State University's Plant Science Farm. The climate model was based on Jensen-Haise's potential evapotranspiration and crop production coefficients (Jensen,

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TABLE 37. GROUNDWATER QUALITY AT THE DEMONSTRATION FARM

1977 Pump No.	Depth of Well* meters	EC x 10^3 mmhos/cm	pH	Ca	Mg	Na	K	Cl	CO_3	HCO_3	SO_4
2	60	0.79									
3	33	1.76									
4	33	1.64									
5	33	0.88	7.61	3.82	1.10	3.72	0.14	1.92	0	3.36	3.84
Mean Standard Deviation	1.27 ± 0.50										
Trickle Well**											
1977	75	0.56	8.09	1.08	0.54	3.77	0.09	1.28	0	3.16	1.32
1976		0.57	7.89	1.74	0.79	3.13	0.28	1.28	0	2.36	1.28

* Static water level is 3 meters, upper portion of well No. 2 is cased off.

** Trickle well has last 3 meters of casing slotted.

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TABLE 38. SOIL COMPOSITION WITH DEPTH OF THE TRICKLE-IRRIGATION WELL AT J. F. APODACA FARM

Depth (meters)	Soil Type
0 - 1.52	Soil
1.52 - 12.20	Sand
12.20 - 19.82	Sand and gravel
19.82 - 20.74	Clay and some sand
20.74 - 22.88	Sand and gravel
22.88 - 31.42	Sand
31.42 - 35.38	Some sand and light brown clay
35.38 - 46.06	Sand and gravel
46.06 - 48.19	Clay (light brown)
48.19 - 55.82	Sand and gravel
55.82 - 58.56	Sand and large gravel
58.56 - 61.92	Grey to light brown clay and gravel
61.92 - 62.52	Sand
62.52 - 64.05	Clay and gravel
64.05 - 64.66	Sand and gravel
64.66 - 67.40	Sand and clay
64.40 - 75.64	Sand and gravel

1973). The information supplied to Agricultural Technology Incorporated for the operation of the model included: solar radiation, temperature, humidity, and wind speed. A field man checked each field once a week to determine the available moisture within the root zone and compared the estimate of moisture depletion to the computer model's recommendation for the next irrigation. Information was supplied to the farmer on the water status at each of his fields and a recommended irrigation date.

TRICKLE-IRRIGATION SYSTEM

Figure 23 shows the orchard and row-crop demonstration area with respect to the well and the main line.

Field 1, which consisted of 1.32 hectares of pecans, was converted from

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flood to trickle-irrigation at the beginning of the demonstration project. A gravel-packed well was drilled in order to supply good quality water for the irrigation system. A 3.7 kw Rusberry submergible turbine pump was installed. The trickle system was used also to irrigate four rows each of tomatoes and peppers.

The system initially had a 200-mesh screen filter which was later supplemented by a sand filter automated to permit backwashing. The sand filter was manufactured by Agricultural Products, Burbank, California.

Soil samples were taken and saturation extracts were prepared in the field. The saturation extracts, and all other water quality samples, were analyzed for salt content at the University's water laboratory using the procedures listed in Table 39.

Infiltration Measurements

Two approaches were investigated to estimate the seepage rate of water from the Demonstration Farm and main supply ditch. The first approach was to measure the infiltration rate in a section of the Upper Chamberino irrigation lateral and several sections of the farm supply ditches by ponding the water.

Bulkheads were fabricated and installed in the irrigation ditches. Test sites, as shows in Figure 22, are locations 4, 6, 7, and 8. Water stage recorders were installed to measure the rate of lowering of the water surface. Testing was conducted until a steady-state condition had occurred. During the infiltration tests the turnouts were sealed by lining with plastic.

The second approach used to determine the infiltration rate for a section of canal was to measure the change in the temperature profile beneath the canal over a 24-hour period. If the infiltration rate normal to the surface reached a steady-state condition and a sinusoidal temperature fluctuation of constant amplitude was assumed at the land surface, the flow of heat and water can be described by:

$$k \frac{\partial^2 T}{\partial z^2} - \nu c_o \rho_o \frac{\partial T}{\partial z} = c\rho \frac{\partial T}{\partial t}$$

where k = heat conductivity of the fluid and medium in combination

T = temperature

z = distance of flow

ν = gross velocity of fluid movement

c_o and ρ_o = specific heat and density of fluid

c and ρ = specific heat and density of fluid and soil in combination

t = time

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Using the above equation, Stallman (1965) describes the downward flow of water determined from temperature measurements. The boundary conditions are not met exclusively in an unlined canal. However, the temperature measurement technique has its advantages over ponding or inflow-outflow techniques in that a pipe can be installed to measure the change in temperature in and beneath a canal without disturbance to the canal or interruption of the irrigation process. The only requirements of this technique are that the water has traveled a sufficient distance so that a steady-state equilibrium has been reached between the water and air temperature and that a radiation load has impinged upon it so that there is a sinusoidal input curve from the irrigation water to the soil beneath. To use this technique, a 1.27 cm diameter pipe was installed to a depth of 2 meters beneath the canal and filled with water. Temperature measurements to a hundredth degree centigrade were then taken at selected depths from the water surface to 1.2 meters beneath the soil surface. The readings were taken at 2-hour intervals for 24 hours.

TABLE 39. TABLE OF METHODS USED TO ANALYZE WATER SAMPLES

Ions Tested	Method	Reference
Calcium	Atomic Absorption Spect.	EPA Report (1971)
Magnesium	Atomic Absorption Spect.	ditto
Sodium	Flame emission	ditto
Potassium	Flame emission	ditto
Carbonate	Titration with H_2SO_4	ditto
Bicarbonate	Titration with H_2SO_4	ditto
Nitrate	Cd reduction	ditto
Phosphorus	Molybdo-blue	ditto
Electrical conductivity		ditto
Sulfate	Nitrochrome-Azo Titration	Rasnich and Nakayama (1973)

RESULTS AND DISCUSSION

Irrigation Scheduling

Jensen (1975) published a review of irrigation water management principles and the probable effects of scientific scheduling on salinity of return

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flow. Jensen attributes the lack of any significant changes in irrigation efficiencies during the past decade to the problems associated with the water management of a complex soil-crop environment system, the lack of economic incentive to make improvements, and ineffective traditional approaches to improve irrigation-water management.

Recommendations by Jensen were incorporated into the demonstration project. The irrigation-scheduling method made available to the farmer was based upon a climatological program backed up by trained field personnel who readily supplied current up-to-date information to the farmer for irrigation scheduling.

An example of information received by the farmer is presented in Table 40. This information includes the last date of irrigation, the rooting depth of the crop, the water-holding capacity of the particular soil, the optimum depletion level in the soil, present depletion level, and a recommended irrigation date. The farmer also received a recommendation of the amount of water to apply, but this was determined by the irrigation scheme such as the length of surface run and the time duration water was turned into each furrow or border currently being used by the farmer. On the Demonstration Farm, the water application amounts were not varied from traditional practices.

The field man also made notes about the conditions within the field, as shown at the bottom of Table 40. This information led to good communication between the field man and farmer. Agricultural Technology also offers other services to the farmer besides irrigation scheduling such as tissue analysis, salinity analysis, and agronomic information. The program offers a complete package which integrates water management into the overall farm-management scheme.

Irrigation scheduling, based upon climatological information coupled with observations by field men, allows scheduling to be done on a scientific basis as much as possible.

An example of the information used in the computer program is represented in Figures 24 and 25. Figure 24 is the plot of the potential evapotranspiration for 1976 and 1977 using the Jensen-Haise method. The potential evapotranspiration is adjusted by using a crop coefficient (k_c) which is presented for wheat, alfalfa, cotton, and barley in Figure 25. The equation to compute actual evapotranspiration is:

$$ET = k_c \times PET.$$

Along with the calculated daily ET, it is necessary to know the water-holding capacity of the soil between field capacity and permanent wilting point and the effective rooting depth of the crop (see Figure 25). This information is used to determine how many days' water supply is left in the root zone before moisture depletion occurs. Irrigation should begin at approximately the 50 percent depletion level. The computer program automatically calculated and printed out the number of days before the next irrigation. The resultant data were then checked and updated by field personnel.

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TABLE 40. EXAMPLE OF THE IRRIGATION SCHEDULE INFORMATION RECEIVED BY THE FARMER

Location - Demonstration Farm

Date: May 5, 1977
Farm No: 8526
Weather: Partly Cloudy
Air Temp: 80°F - 1:00 p.m.

Field No.	Crop	Last Irrig	Root Depth	Hold Cap	Acres	Depletions Bpt	Depletions Pres	Irrig Date	Amt to Apply
H1N	Peppers	4-28	2"	2.0		1.0"	.05	2 weeks	
H1S	Tomatoes	4-21	4"	2.0		1.0"	.20	2 weeks	
H3	Tomatoes	4-07	12"	2.0		1.6"	.80	5-12	
H4	Cotton	5-05	6"	2.0			.00	Watering now	
H5	Cotton		6"	2.0		2.4	.30	3 weeks	
H6	Tomatoes	4-21	4"	2.0		1.0	.10	2 weeks	
H7	Alfalfa	5-04	18"	2.0		1.6	.00	Just watered	
H8	Cotton		6"	2.0		2.4	.20	3 weeks	
H9	Cotton		6"	1.8		2.4	.25	3 weeks	
H10	Alfalfa	5-02	48"	1.6		2.0	.00	Just watered	
H11	Tomatoes	4-28	2"	2.0					
			* * FIELD NOTATIONS * *						
H12N	Peppers	5-05	-	2.0		1.0	.00	Watering now	
H12S	Cotton			1.8		2.4	.20	3 weeks	

*FIELD NOTATIONS: The only thing close to needing an irrigation is Field H3. The lighter spots will be ready for an irrigation by next Thursday.

The cotton needs only warm weather and sunshine for the next several weeks. Irrigation is the worst thing you can do to a good stand of cotton at this time.

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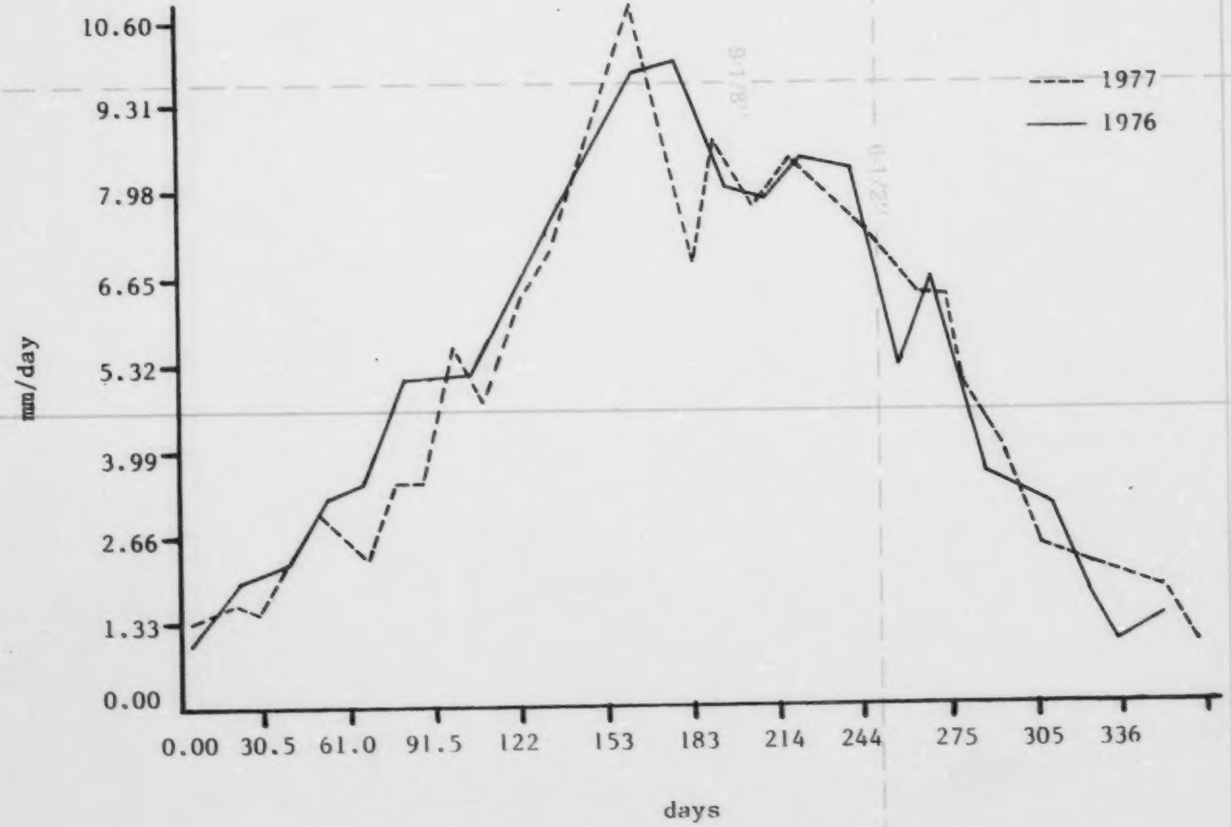

Figure 24. Potential evapotranspiration at the Plant Science Farm.

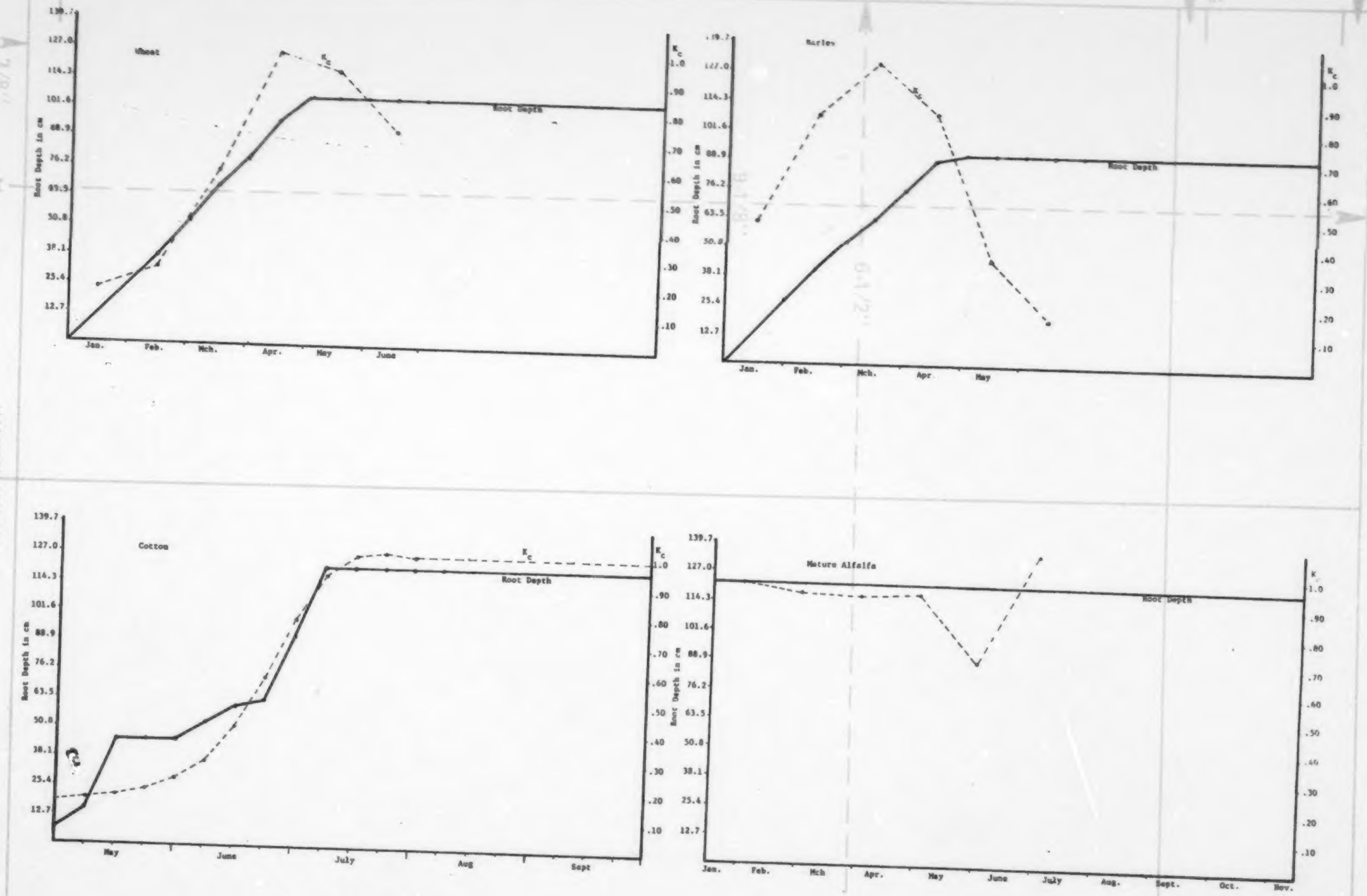

Figure 25. Crop coefficients and root depths for selected crops in the Mesilla Valley, New Mexico

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Farm Irrigation Efficiency

Because the mean annual precipitation averages less than 25 cm in the Mesilla Valley the consumptive-use requirements of the crops were satisfied mainly by irrigation. Irrigation efficiency is the ratio of consumptive use to irrigation applied plus rainfall. Consumptive use is dependent upon the yield of the crop. It is normally measured under non-limiting moisture conditions that maximize yield. Tables 41 through 46 present computed consumptive-use data used and computed field irrigation efficiencies. The consumptive-use data selected was based on the best available data. Different irrigation efficiencies would be determined if other methods were used to compute the consumptive use of the crop.

Irrigation scheduling on the Demonstration Farm resulted in an overall computed farm irrigation efficiency of 65 percent for 1976, and 63 percent for 1977. Farm irrigation efficiencies measured in other states by several investigators ranged from 35 to 65 percent with an average of between 40 and 50 percent (Willardson, 1972; Tyler, et al., 1964; U.S. Dept. of Interior, Bureau of Reclamation, 1971 and 1973; Advisory Committee, 1974).

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It was observed that although the overall farm irrigation efficiency was above average, the field-by-field irrigation efficiencies varied considerably, ranging from 35 to 100 percent. The efficiencies also varied considerably for each particular crop, preventing any correlation between field irrigation efficiencies and particular crops. The efficiency of alfalfa varied from 93 percent in 1976 for Field No. 10 to 76 percent in 1977 for Fields 7 and 10. In 1976, the cotton efficiencies ranged from 63 to 84 percent. In 1977, the cotton efficiencies varied from 48 percent for Field No. 9 to 91 percent for Field No. 5.

The farm irrigation efficiency did not increase when the more expensive well water was used predominantly in 1977, as compared to river water in 1976.

Gas Consumption and Pump Efficiencies

The five wells used on the Demonstration Farm had turbine pumps with power supplied by Waukesha and Minneapolis Moline engines operating on natural gas.

Figure 26 presents the gas consumption per unit of water pumped for the different wells. Pump efficiency is also presented in Figure 26. In general, the overall pumping-plant efficiencies were around 10 percent, pump efficiencies ranged from 44 to 60 percent, and engine efficiencies ranged from 16 to 20 percent. Pumping-plant efficiencies could be improved by increased maintenance and replacement and by proper selection of engine and pump sizes for the specified lifts and flow encountered in the Mesilla Valley. A new pumping plant operated on natural gas should have an overall efficiency of 15 percent (Buckingham, 1978).

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TABLE 41. IRRIGATION WATER APPLICATION, IRRIGATION EFFICIENCY, AND COMPUTED EVAPOTRANSPIRATION FOR ALFALFA ON THE DEMONSTRATION FARM

Irrigation Date	Recommended Irrigation Date	Total Water Applied	Application per hectare	Source of Water	Rainfall	Evapotranspiration (ET) for time period
		(km^3)	(ha-cm/ha)		(ha-cm/ha)	(ha-cm/ha)
Alfalfa-Fd. 10 (28.1 hectares)						
1-01-76	--	--	--	--	--	--
3-15-76	3-17-76	46.34	16.4	S *	--	10.4
5-18-76	5-13-76	25.02	8.8	G **	1.7	19.9
6-03-76	6-08-76	72.34	25.6	G	0.3	9.8
6-22-76	6-24-76	65.86	23.3	--	2.0	12.6
7-12-76	7-10-76	57.31	20.2	S	1.0	14.2
8-07-76	8-05-76	32.50	11.6	S	4.5	22.5
8-20-76	8-21-76	37.63	13.4	S	0.3	22.8
9-19-76	9-18-76	37.63	13.4	S	6.7	33.9
10-08-76	10-07-76	41.91	14.9	S	1.4	7.8
Season Total		416.54	147.8		18.0	154.1 †
Percentage Surface Water		60.7%				
Seasonal Field Irrigation Efficiency		92.9%				
Alfalfa-Fe. 7 (16.48 hectares) Planted 3-26-77 - Harvested 4 times during season						
3-26-77	--	--	--	--	--	--
3-27-77	pre-irrigate	13.19	8.0	G	1.2	--
4-05-77	--	16.35	10.0	G	--	0.7
5-03-77	--	13.17	8.0	G	--	6.9
5-22-77	5-23-77	25.15	15.3	G	0.2	4.5
6-06-77	6-06-77	24.59	14.9	G	0.1	12.5
6-27-77	6-24-77	22.34	13.6	G	--	18.6
7-13-77	7-15-77	19.56	11.9	G & S	4.8	17.4
8-14-77	8-12-77	31.31	19.0	G	2.2	27.2
9-02-77	--	32.20	19.5	G	3.3	12.6
9-30-77	--	22.08	13.4	G	0.7	5.2
10-28-77	--	--	--	--	--	5.9
Season Total		219.94	133.6		12.5	111.5
Percentage Surface Water		8%				
Seasonal Field Irrigation Efficiency		76%				
Alfalfa-Fd. 10 (28.11 hectares) Planted 1974 - Harvested 4 times during season						
1-01-77	--	--	--	--	--	--
3-11-77	--	63.84	22.7	G	1.8	8.8
4-11-77	4-13-77	40.29	14.3	G	1.2	12.9
5-02-77	4-28-77	39.54	14.1	G	--	21.7
5-23-77	5-23-77	65.72	23.4	G	0.2	10.2
6-07-77	6-08-77	65.98	23.5	G	0.1	20.0
6-30-77	6-29-77	66.77	23.8	G	1.0	18.6
7-14-77	7-14-77	56.79	20.2	S	3.8	20.7
8-09-77	8-04-77	64.45	22.9	G	1.5	17.3
8-23-77	--	56.53	20.1	G	1.0	18.7
9-15-77	--	54.51	19.4	G	3.7	8.7
10-28-77	--	--	--	--	2.1	10.9
Season Total		574.42	204.4		16.4	168.5
Percentage Surface Water		10%				
Seasonal Field Irrigation Efficiency		76%				

* S - Surface Water

** G - Groundwater from well

† Based on measurement by the Agricultural Engineering Department at the Plant Science Farm New Mexico State University

TABLE 42. IRRIGATION WATER APPLICATION, IRRIGATION EFFICIENCY, AND COMPUTED EVAPOTRANSPIRATION FOR COTTON ON THE DEMONSTRATION FARM

Irrigation Date	Recommended Irrigation Date	Total Water Applied	Application per hectare	Source of Water	Rainfall	Evapotranspiration (ET) for time period
		(ha-cm/ha)			(ha-cm/ha)	(ha-cm/ha)
Cotton-Fd 4 West (16.2 hectares)						
3-27-76	pre-irrigate	39.93	24.5	S*	--	1.5
5-12-76	NI ††	15.40	9.4	G**	1.7	7.6
6-28-76	6-30-76	17.99	11.1	S	2.3	20.5
8-05-76	7-31-76	16.27	10.1	S	5.5	6.6
8-17-76	8-22-76	13.19	8.1	S	0.1	6.1
8-28-76	9-02-76	12.94	7.8	S	0.2	17.7
10-27-76	--	--	--	--	8.1	--
Season Total		115.73	71.1		18.0	60.0†
Percentage Surface Water		87.0%				
Seasonal Field Irrigation Efficiency		67.3%				
Cotton-Fd. 9 (10.7 hectares)						
3-29-76	pre-irrigate	24.65	23.0	S	--	--
5-18-76	NI	9.86	9.1	S	1.7	1.8
6-22-76	7-01-76	15.61	14.7	S	2.3	5.3
8-07-76	8-05-76	12.36	11.4	S	5.5	23.0
8-27-76	finished	21.07	19.7	G	0.4	11.4
10-05-76	--	--	--	--	8.1	13.9
10-27-76	--	--	--	--	--	4.3
Season Total		83.57	77.9		18.0	59.7
Percentage Surface Water		75.0%				
Seasonal Field Irrigation Efficiency		62.2%				
Cotton-Fd. 12 (6.8 hectares)						
3-19-76	pre-irrigate	5.02	7.3	S	--	--
5-13-76	NI	5.18	7.6	S	1.8	1.8
6-29-76	7-01-76	6.83	10.1	G	5.3	7.6
7-25-76	7-22-76	6.83	10.1	S	2.7	13.4
8-21-76	8-26-76	6.20	9.1	S	3.2	15.4
8-26-76	--	6.42	9.4	G	7.6	3.0
9-26-76	--	--	--	--	0.5	12.9
10-27-76	--	--	--	--	--	5.8
Season Total		36.48	53.6		18.0	60.0
Percentage Surface Water		63.0%				
Seasonal Field Irrigation Efficiency		83.8%				
Cotton-Fd. 4 (27.94 hectares) Planted 4-19-77 - Harvested 11-3-77						
3-19-77	pre-irrigate	51.35	18.4	S	--	--
5-03-77	5-05-77	15.08	5.4	G	--	0.9
6-27-77	6-27-77	26.84	9.6	G	0.3	12.1
6-29-77	6-27-77	28.38	10.2	S	0.2	0.6
8-02-77	7-30-77	27.73	9.9	S	6.3	21.8
8-19-77	8-22-77	48.03	17.2	G	0.8	10.6
10-28-77	First freeze	--	--		6.0	21.4
Season Total		197.41	70.7		13.6	67.4
Percentage Surface Water		54%				
Seasonal Field Irrigation Efficiency		80%				

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TABLE 42. (Continued)

Irrigation Date	Recommended Irrigation Date	Total Water Applied (km^3)	Application per hectare (ha-cm/ha)	Source of Water	Rainfall (ha-cm/ha)	Evapotranspiration (ET) for time period (ha-cm/ha)
Cotton-Fd. 5 (5.55 hectares) Planted 4-18-77 - Harvested 10-23-77						
3-27-77	pre-irrigate	5.14	9.3	G	--	--
5-25-77	5-30-77	7.18	12.9	S	0.2	3.1
6-15-77	6-25-77	4.05	7.3	G	0.1	4.7
7-21-77	7-18-77	8.38	15.1	G	4.8	19.2
8-22-77	8-14-77	8.59	15.5	G	2.5	20.8
10-28-77	--	--	--	--	5.8	19.3
Season Total		33.34	60.1		13.4	67.1
Percentage Surface Water		14%				
Seasonal Field Irrigation Efficiency		91%				
Cotton-Fd. 8 (13.52 hectares) - Planted 4-16-77 - Harvested 10-15-77						
3-28-77	pre-irrigate	15.81	11.7	--	--	--
5-25-77	5-26-77	20.12	14.9	S	0.2	3.1
7-04-77	6-24-77	16.34	12.1	G	1.3	13.2
7-31-77	7-30-77	13.20	9.8	G	5.3	18.0
8-19-77	8-17-77	21.81	16.1	G	0.8	11.2
9-05-77	--	15.81	11.7	S	3.2	8.8
9-23-77	--	22.19	16.4	G	0.7	6.3
10-05-77	--	19.58	14.5	G	1.0	2.8
10-28-77	--	--	--	--	1.0	2.7
Season Total		144.86	107.2		13.5	66.1
Percentage Surface Water		28%				
Seasonal Field Irrigation Efficiency		55%				
Cotton-Fd. 9 (10.69 hectares) - Planted 4-17-77 - Harvested 10-29-77						
3-28-77	pre-irrigate	15.77	14.8	G	--	--
5-25-77	5-26-77	17.25	16.1	S	0.2	3.2
6-12-77	6-17-77	18.95	17.7	G	0.1	3.6
7-20-77	7-19-77	15.96	14.9	G	4.8	19.8
8-08-77	8-12-77	16.33	15.3	G	1.5	12.9
8-17-77	8-26-77	15.81	14.8	S	0.7	5.2
8-29-77	--	16.54	15.5	G	0.3	6.9
9-15-77	--	16.34	15.3	G	3.7	7.0
10-28-77	--	--	--	--	2.1	8.1
Season Total		132.95	124.4		13.4	66.7
Percentage Surface Water		25%				
Seasonal Field Irrigation Efficiency		48%				
Cotton-Fd. 12 South (3.24 hectares) - Planted 4-22-77 - Harvested 10-28-77						
3-28-77	pre-irrigate	2.97	9.2	--	--	--
5-11-77	--	3.76	11.6	G	0.2	1.4
6-30-77	--	3.54	10.9	G	1.1	12.4
8-09-77	--	4.65	14.4	G	5.3	26.3
9-23-77	--	5.17	16.0	G	4.7	20.9
10-03-77	--	5.21	15.7	G	0.3	2.6
10-28-77	--	--	--	--	2.0	3.0
Season Total		25.30	77.8		13.6	66.6
Percentage Surface Water		0%				
Seasonal Field Irrrigation Efficiency		72%				

* S - Surface Water
** G - Groundwater from well
+ Based on climatic program used by agricultural technology
†† No irrigation recommended

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TABLE 43. IRRIGATION WATER APPLICATION, IRRIGATION EFFICIENCY, AND COMPUTED EVAPOTRANSPIRATION FOR LETTUCE ON THE DEMONSTRATION FARM

Irrigation Date	Recommended Irrigation Date	Total Water Applied	Application per Hectare	Source of Water	Rainfall	Evapotranspiration (ET) for time period
		(km^3)	(ha-cm/ha)		(ha-cm/ha)	(ha-cm/ha)
Lettuce-Fd. 3 (20.2 hectares)						
7-23-76	None	16.64	8.2	S*	--	--
8-04-76	"	12.22	6.0	S	2.8	--
8-08-76	"	41.04	20.3	S(52%)	--	--
8-18-76	"	11.50	5.7	S	0.3	--
8-21-76	"	32.66	16.2	S(37%)	--	--
8-29-76	"	16.93	8.4	S	--	--
9-16-76	"	12.31	6.1	S	6.7	--
9-27-76	"	31.80	15.7	S(68%)	0.6	--
10-13-76	"	14.66	7.3	G**	0.8	--
11-04-76	"	14.04	7.0	G	0.7	--
Season Total		203.81	100.9		12.0	45.0†
Percentage Surface Water		41.0%				
Seasonal Field Irrigation Efficiency		39.8%				
Lettuce-Fd. 2 North (2.43 hectares) Planted 8-1-77 - Plowed under 9-1-77						
8-02-77	--	3.06	12.6	G	--	--
8-04-77	--	3.68	15.1	G	--	--
8-07-77	--	2.12	8.7	G	--	--
Season Total		8.86	36.4		0.0	22.3
Percentage of Surface Water		0 %				
Lettuce-Fd. 11 (8.10 hectares) Planted 8-1-77 - Plowed under 9-1-77						
8-02-77	--	12.79	15.8	G	--	--
8-12-77	--	11.52	14.2	G	0.6	--
Season Total		24.31	30.0		0.6	22.3
Percentage of Surface Water		0 %				
Lettuce-Fd. 12 North (3.24 hectares) Planted 7-31-77 - Plowed under 9-1-77						
7-31-77	--	--	--	G	--	
8-02-77	8-01-77	2.75	8.5	G	--	--
8-11-77	8-11-77	2.22	6.8	G	0.2	--
8-19-77	--	1.91	5.9	G	0.6	--
Season Total		6.88	21.2		0.8	22.3
Percentage of Surface Water		0 %				

* S - Surface Water
** G - Ground Water
† Gregory, E. J. and Eldon G. Hanson, Predicting Consumptive Use with Climatological Data, New Mexico Water Resource Research Institute, Report No. 066, April 1976

Trickle-Irrigation System Used to Irrigate a Pecan Orchard

The pecan orchard at the Demonstration Farm was under trickle-irrigation for two years. Applied water data are presented in Tables 47 and 48.

Using a water-balance technique, measurements were made on the consumptive use of pecan orchards at New Mexico State University's Plant Science

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TABLE 44. IRRIGATION WATER APPLICATION, IRRIGATION EFFICIENCY, AND COMPUTED EVAPOTRANSPIRATION FOR PEPPERS ON THE DEMONSTRATION FARM

Irrigation Date	Recommended Irrigation Date	Total Water Applied	Application per Hectare	Source of Water	Rainfall	Evapotranspiration (ET) for time period
		(km^3)	(ha-cm/ha)		(ha-cm/ha)	(ha-cm/ha)
Peppers-Fd. 2 (5.5 hectares)						
4-12-76	pre-irrigate	6.16	11.1	S*	--	--
4-22-76	--	3.20	5.8	S	1.2	--
5-12-76	--	3.82	6.8	G**	0.5	--
5-15-76	5-15-76	4.81	8.6	S	0.3	--
6-02-76	6-02-76	8.24	14.9	G	2.0	--
6-20-76	6-30-76	8.26	14.0	G	1.0	--
7-08-76	7-16-76	5.54	10.1	G	--	--
8-08-76	8-05-76	5.61	10.1	G	3.7	--
8-18-76	8-17-76	8.21	14.9	S	0.3	--
9-02-76	9-01-76	7.15	12.9	S	--	--
9-27-76	9-21-76	7.21	13.2	S(55%)	7.3	--
10-05-76	--	--	--	-	0.8	--
Season Total		68.21	123.4		17.2	77.9†
Percentage Surface Water			54.0%			
Seasonal Field Irrigation Efficiency			55.4%			
Peppers-Fd. 7 (10.3 hectares) Plus - Grain Sorghum (5.7 hectares)						
5-14-76	5-14-76	9.21	5.6	S	--	--
5-18-76	--	11.21	6.8	S	--	--
5-20-76	6-03-76	11.03	6.6	G	0.3	--
6-12-76	6-20-76	16.54	10.1	S	2.0	--
6-26-76	7-02-76	18.98	11.4	G	--	--
7-15-76	7-13-76	19.72	11.9	S	1.8	--
8-02-76	8-03-76	12.54	7.6	S	3.7	--
8-20-76	8-18-76	35.37	21.5	G	0.4	--
9-03-76	9-02-76	18.49	11.1	S	--	--
9-21-76	9-21-76	6.14	3.8	S	6.7	--
10-01-76	--	13.19	8.1	S	0.8	--
Season Total		172.42	104.5		15.7	71.2† ††
Percentage Surface Water			62.0%			
Seasonal Field Irrigation Efficiency			64.8%			
Peppers-Fd. 4 East (11.7 hectares)						
3-13-76	pre-irrigate	27.85	23.8	S	--	--
6-04-76	6-13-76	10.60	9.1	S	2.1	--
6-22-76	6-31-76	17.25	14.7	S	2.0	--
7-12-76	7-10-76	14.29	12.1	S	1.0	--
8-05-76	7-31-76	14.87	9.9	S	4.5	--
8-18-76	8-17-76	13.06	11.1	S	0.3	--
8-28-76	8-27-76	20.33	17.2	G	--	--
10-05-76	9-20-76	11.71	9.9	G	8.1	--
Season Total		126.89	107.8		18.1	77.9
Percentage Surface Water			75.0%			
Seasonal Field Irrigation Efficiency			61.9%			
Peppers-Fd. 12 North (3.24 hectares) Planted 4-22-77 - Plowed under 7-7-77						
3-28-77	pre-irrigate	2.97	9.2	G	--	--
5-05-77	--	4.39	13.5	G	0.2	--
5-11-77	--	3.25	10.0	G	--	--
6-30-77	7-04-77	3.60	11.1	G	1.1	--
Season Total		14.21	43.8		1.3	24.2
Percentage of Surface Water			0 %			

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TABLE 44. (Continued)

Irrigation Date	Recommended Irrigation Date	Total Water Applied	Application per Hectare	Source of Water	Rainfall	Evapotranspiration (ET) for time period
		(km^3)	(ha-cm/ha)		(ha-cm/ha)	(ha-cm/ha)
Peppers-Fd. 2 North (2.43 hectares) Planted 4-8-77 - Plowed under 7-1-77						
4-12-77	--	1.82	7.5	S	--	--
4-20-77	--	2.16	8.9	G	--	--
5-16-77	--	3.20	13.2	G	0.2	--
5-25-77	5-26-77	3.72	15.3	G	--	--
6-14-77	6-17-77	2.13	8.8	G	0.1	--
7-01-77	Plowed under; poor stand					
Season Total		13.03	53.7		0.3	28.1
Percentage of Surface Water			8.0%			

* S - Surface Water

** G - Groundwater from well

† Consumptive Irrigation Requirements of Selected Irrigated Areas in New Mexico, New Mexico State University Agricultural Experiment Station Bulletin 531, Henderson and Sorensen, August 1968

†† Weighted average of grain sorghum and peppers according to hectares planted

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TABLE 45. IRRIGATION WATER APPLICATION, IRRIGATION EFFICIENCY, AND COMPUTED EVAPOTRANSPIRATION FOR TOMATOES ON THE DEMONSTRATION FARM

Irrigation Date	Recommended Irrigation Date	Total Water Applied	Application per Hectare	Source of Water	Rainfall	Evapotranspiration (ET) for time period
		(km^3)	(ha-cm/ha)		(ha-cm/ha)	(ha-cm/ha)
Tomatoes-Fd. 8 (13.5 hectares)						
3-20-76	--	23.42	17.3	S*	--	--
3-23-76	--	27.73	20.5	S	--	--
5-01-76	5-01-76	19.72	14.6	S	1.3	--
5-07-76	5-07-76	6.53	4.8	S	0.5	--
6-17-76	6-13-76	10.23	7.6	S	2.3	--
7-13-76	7-10-76	11.95	8.8	S	1.0	--
8-04-76	8-02-76	14.82	11.0	G**	4.5	--
8-20-76	finished	1.64	1.2	G	0.3	--
Season Total		116.04	85.8		10.0	57.7†
Percentage Surface Water			85.8%			
Seasonal Field Irrigation Efficiency			60.2%			
Tomatoes-Fd. 11 (25.1 hectares)						
5-18-76	5-18-76	42.00	16.7	S	--	--
6-22-76	6-20-76	83.19	33.1	S & G	2.0	--
7-22-76	7-15-76	32.04	12.6	G	1.8	--
8-03-76	NI	6.16	2.5	G	3.7	--
8-07-76	8-05-76	28.96	11.4	S	--	--
8-27-76	8-22-76	22.08	8.9	G	0.3	--
8-31-76	NI	15.30	6.1	G	--	--
9-29-76	finished	--	--	-	7.4	--
Season Total		229.74	91.3		15.3	57.7
Percentage Surface Water			35.9%			
Seasonal Field Irrigation Efficiency			54.1%			
Tomatoes-Fd. 2 South (2.84 hectares) Planted 4-8-77 - Harvested 8-29-77						
4-12-77	--	2.23	7.8	S	--	--
4-20-77	--	2.50	8.8	G	--	--
5-16-77	--	3.92	13.8	G	0.2	--
5-25-77	5-26-77	4.56	16.0	G	--	--
6-14-77	6-17-77	2.60	9.2	G	0.1	--
7-01-77	7-02-77	3.15	11.1	G	1.0	--
7-12-77	7-12-77	3.57	12.6	G	3.8	--
7-20-77	7-21-77	2.59	9.1	G	--	--
8-02-77	8-01-77	3.35	11.8	G	1.5	--
8-04-77	8-11-77	2.70	9.5	G	--	--
8-07-77	--	2.33	8.2	G	--	--
Season Total		33.50	117.9		6.6	57.7
Percentage Surface Water			8 %			
Seasonal Field Irrigation Efficiency			46.0%			
Tomatoes-Fd. 3 (29.97 hectares) Planted 3-21-77 - Harvested 8-18-77						
3-21-77	--	--	--	-	--	--
3-26-77	--	19.94	6.6	G	1.2	--
3-30-77	--	36.15	12.1	S	--	--
4-07-77	--	9.86	3.3	S	--	--
4-12-77	4-21-77	13.15	4.4	S	--	--
4-19-77	--	3.70	1.2	S	--	--
5-16-77	5-12-77	38.50	12.8	G	0.2	--
6-06-77	6-06-77	32.53	10.8	G	0.1	--
6-22-77	6-22-77	18.89	6.3	S	--	--
7-01-77	7-04-77	38.72	12.9	S	1.0	--
7-14-77	7-13-77	17.14	5.7	G & S	3.8	--
7-21-77	7-23-77	31.68	10.6	G & S	--	--
8-07-77	8-04-77	14.79	4.9	S	1.5	--
Season Total		275.05	91.6		7.8	57.7
Percentage Surface Water			58.0%			
Seasonal Field Irrigation Efficiency			58.0%			

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TABLE 45. (Continued)

Irrigation Date	Recommended Irrigation Date	Total Water Applied (km³)	Application per Hectare (ha-cm/ha)	Source of Water	Rainfall (ha-cm/ha)	Evapotranspiration (ET) for time period (ha-cm/ha)
Tomatoes-Fd. 6 (7.70 hectares) Planted 4-12-77 - Harvested 8-29-77						
3-26-77	pre-irrigate	7.85	10.2	G	--	--
4-15-77	4-21-77	13.45	17.5	S	--	--
5-29-77	6-02-77	5.67	7.4	G	0.2	--
6-15-77	6-25-77	5.50	7.1	G	0.1	--
6-29-77	7-09-77	7.22	9.4	G	0.2	--
7-13-77	7-13-77	7.59	9.8	G & S	4.6	--
7-21-77	7-22-77	11.58	15.0	G	--	--
8-02-77	8-04-77	9.29	12.1	G	1.5	--
Season Total		68.15	88.5		6.6	57.7
Percentage Surface Water			29.0%			
Seasonal Field Irrigation Efficiency			61.0%			
Tomatoes-Fd. 11 (25.11 hectares) Planted 4-17-77 - Harvested 9-2-77						
4-26-77	4-28-77	53.73	21.4	G	--	--
5-02-77	--	42.79	17.0	S	--	--
5-11-77	--	51.33	20.4	G	0.2	--
5-25-77	6-02-77	46.49	18.5	G & S	--	--
5-30-77	--	17.75	7.1	G	--	--
6-13-77	6-09-77	30.53	12.2	G	0.1	--
6-18-77	--	34.27	13.6	G	--	--
6-28-77	6-27-77	25.61	10.2	G	--	--
7-01-77	6-30-77	26.88	10.7	G	1.0	--
7-14-77	7-15-77	14.90	5.9	G	3.8	--
7-20-77	7-19-77	17.05	6.8	G	--	--
7-30-77	7-27-77	14.43	5.7	G	1.5	--
8-05-77	8-05-77	26.02	10.4	G	--	--
Season Total		401.78	159.9		6.6	57.7
Percentage of Surface Water			19.0%			
Seasonal Field Irrigation Efficiency			35.0%			

* S - Surface Water

** G - Groundwater from well

† Seasonal estimate based on minimum value measured in San Joaquin Valley, California, Vegetative Water Use, Bulletin 113-3, Department of Water Resources, California, MacGilvray, N. A. 1975.

Farm. The trees were 2-3 years younger than those at the Demonstration Farm and were flood irrigated. They would have had larger evaporation losses than the trees irrigated by the trickle-irrigation system. Preliminary 1976 data for the Plant Science Farm orchards indicated a higher consumptive use than originally expected. Consumptive use measured for 1977 was 65.7 ha-cm/ ha. It was felt that the difference between the applied water plus rainfall at the Demonstration Farm in 1976 (40.3 ha-cm/ha) and the measured consumptive use at the Plant Science Farm in 1977 (65.7 ha-cm/ha) was not due entirely to additional evaporation losses caused by surface-irrigation, but that the Demonstration Farm trees were stressed for moisture in 1976, depleting the soil moisture reservoir and probably consumptively using less water than measured at the Plant Science Farm in 1977. Based on preliminary 1976 Plant Science Farm consumptive-use data, additional water was applied to the Demonstration Farm in 1977 with a flood irrigation at the start of the growing season. This resulted in an irrigation efficiency computed to be 105 percent.

The extra five percent was probably due to experimental error. Yield from the trickle-irrigated pecan orchard was 1214 kg/ha. The average yield in the Mesilla Valley for a pecan orchard of this age is approximately 784-

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TABLE 46. IRRIGATION WATER APPLICATION, IRRIGATION EFFICIENCY, AND COMPUTED EVAPOTRANSPIRATION FOR WHEAT ON THE DEMONSTRATION FARM

Irrigation Date	Recommended Irrigation Date	Total Water Applied (km^3)	Application per Hectare (ha-cm/ha)	Source of Water	Rainfall (ha-cm/ha)	Evapotranspiration (ET) for time period (ha-cm/ha)
Wheat-Fd. 3 (30.0 hectares)						
1-13-76	--	40.87	13.7	G**	--	--
3-14-76	3-17-76	41.90	13.9	S*	1.0	4.8
4-07-76	4-08-76	42.52	14.2	S	0.1	8.6
4-29-76	4-27-76	42.89	14.2	S	1.2	7.6
5-13-76	5-12-76	26.25	8.9	S	0.5	5.8
7-12-76	harvested	--	--	-	3.0	11.6
Season Total		194.43	64.8		6.0	38.5†
Percentage Surface Water			79.0%			
Seasonal Field Irrigation Efficiency			54.5%			
Wheat-Fd. 5 & 6 (13.2 hectares)						
1-28-76	NI	19.22	14.6	S	--	--
3-26-76	3-26-76	15.40	11.7	S	1.0	8.6
4-22-76	4-23-76	35.00	26.5	S	1.3	9.4
5-18-76	5-16-76	22.17	16.8	S	0.5	11.4
6-16-76	harvested	--	--	-	2.3	8.1
Season Total		91.80	69.6		5.1	37.4†
Percentage Surface Water			100.0%			
Seasonal Field Irrigation Efficiency			50.0%			

* S - Surface Water
** G - Groundwater from well
† Based on climatic program used by agricultural technology

1009 kg/ha. The trickle yields were comparable to those obtained under flood irrigation but represented a great savings in water. Under a typical flood irrigation, 73-97 ha-cm/ha of water would be applied, compared to 47 ha-cm/ha under trickle-irrigation near a 100 percent irrigation efficiency, assuming a normal rainfall year.

Trickle-Irrigation and the Plant Water Potential of Pecan Trees

During the summer months of 1977, the trickle-irrigated pecan orchard received water at a rate of approximately 0.15 m^3 per day per tree. Plant water potential measurements (Slatyer, 1967) were made to determine if the trees were responding as they would under conventional irrigation techniques. Figure 27 is a plot of the daily plant water potential cycle comparing the drip-irrigated with flood-irrigated trees. The plant water potential at night approached the soil water potential where the minimum value observed was approximately 1.6 bars. Measurements were made on August 10, after the drip system had been shut off for four days to allow the foreman to cultivate the field. The results showed a higher peak for the drip-irrigated trees than the flood-irrigated trees indicating that the drip-irrigated plants were undergoing a slight stress. The available soil water reservoir, irrigated by the drip system, was small and the four days appeared to be sufficient to deplete the reservoir. Comparing the two systems, the midday reading indicated that the drip- and flood-irrigated pecan trees were very close in plant water potential when the drip system is operated according to schedule.

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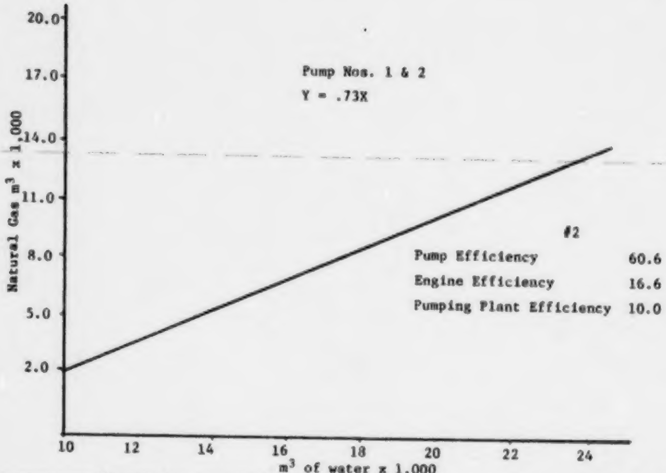
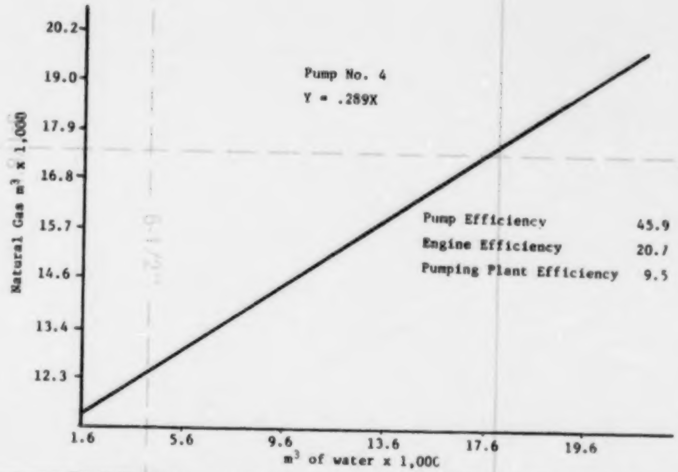
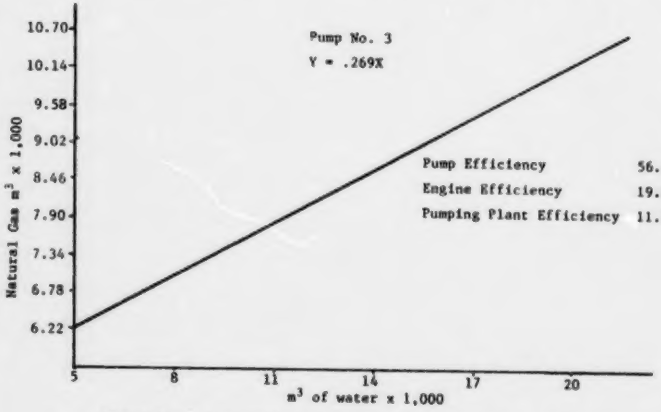


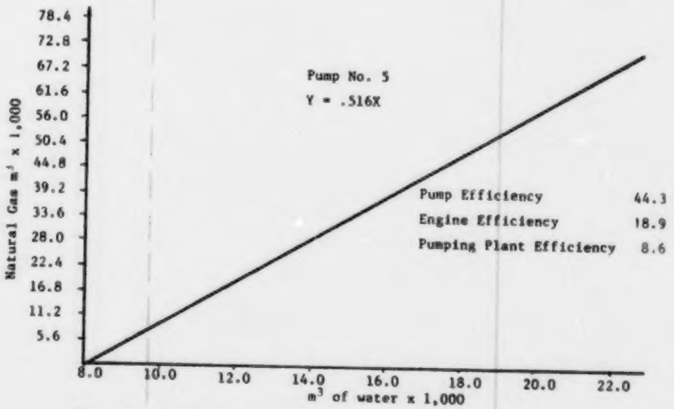
Natural gas consumption vs. water pumped for Pumps 1 & 2, Demonstration Farm



Natural gas consumption vs. water pumped for Pump 4, Demonstration Farm



Natural gas consumption vs. water pumped for Pump 3, Demonstration Farm



Natural gas consumption vs. water pumped for Pump 5, Demonstration Farm

Figure 26. Natural gas consumption vs. water pumped for wells on the Demonstration Farm

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TABLE 47. APPLIED WATER FOR THE DEMONSTRATION FARM IN 1975 AND 1976

Irrigation Period	Total Water Applied Per Tree*	Average Daily Water Applied Per Tree	Total Water Applied	Rainfall	Evapotranspiration (ET)
	m^3/tree	m^3	ha-cm/ha	ha-cm/ha	ha-cm/ha
Pecans (1.32 hectares)					
5-12-75 to 5-19-76	.477	.0596	1.19	1.7	
5-20-75 to 5-27-76	.483	.0604	1.21	0.3	
5-28-76 to 6-04-76	.354	.0590	0.88	-	
6-05-76 to 6-18-76	1.468	.1840	3.67	2.0	
6-19-76 to 7-01-76	.285	.0260	0.71	-	
7-02-76 to 7-10-76	.424	.0471	1.06	1.0	
7-11-76 to 7-17-76	.428	.0610	1.06	0.8	
7-18-76 to 7-29-76	.245	.0310	0.61	2.6	
7-30-76 to 8-05-76	.829	.1184	2.07	1.1	
8-06-76 to 8-27-76	2.078	.0945	5.21	0.4	
8-28-76 to 9-07-76	.435	.0650	1.47	3.5	
9-08-76 to 9-14-76	.175	.0250	0.43	3.2	
9-22-76 to 10-01-76	1.073	.1073	2.68	0.9	
First Freeze - 10-08-76				0.6	
Season Total	8.754	.938	22.25	18.1	65.7

* 326 Trees

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TABLE 48. APPLIED WATER FOR THE DEMONSTRATION FARM IN 1977

Irrigation Period	Total Water Applied Per Tree	Average Daily Water Applied Per Tree	Total Water Applied	Rainfall	Evapotranspiration (ET)
	m^3/tree	m^3	ha-cm/ha	ha-cm/ha	ha-cm/ha
Pecans (1.32 hectares)					
1-01-77 to 4-07-77			12.45	–	
4-08-77 to 4-28-77	1.153	.058	2.78	–	
4-29-77 to 5-20-77	.421	.020	1.01	0.4	
5-21-77 to 5-27-77	.290	.048	0.73	–	
5-28-77 to 6-03-77	.997	.166	2.39	0.1	
6-04-77 to 4-14-77	.444	.044	1.09	–	
6-15-77 to 6-22-77	.493	.070	1.19	–	
6-23-77 to 6-29-77	.290	.048	0.73	0.2	
6-30-77 to 7-05-77	.483	.080	1.19	5.0	
7-06-77 to 7-18-77	1.707	.142	4.12	–	
7-19-77 to 7-26-77	1.032	.147	2.48	1.2	
7-27-77 to 8-02-77	.959	.160	2.28	0.6	
8-03-77 to 8-09-77	2.432	.405	5.89	–	
8-10-77 to 8-24-77	2.108	.151	5.14	1.0	
8-24-77 to 9-03-77	1.442	.144	3.49	1.9	
First Freeze					
10-28					
Season Total	14.251		46.96	15.5	65.7

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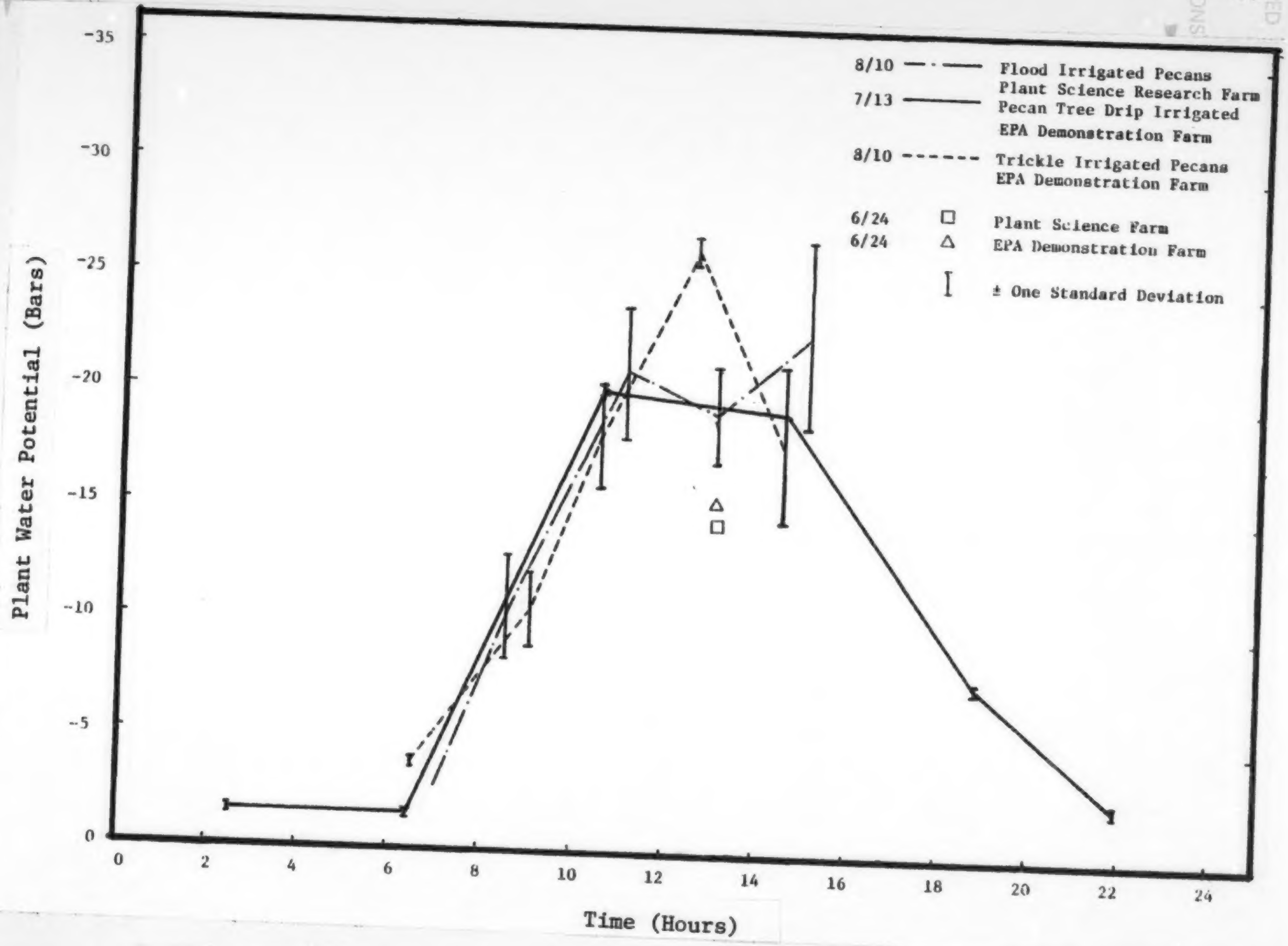

Figure 27. Plant water potential for a pecan tree irrigated under drip and flood irrigation (1977)

Drip-Irrigation of Row Crops

Applied water information for the drip-irrigated row crop demonstration of tomatoes and peppers is presented in Table 49. The seasonal irrigation efficiency was 48.5 percent for the tomatoes and 65.6 percent for the peppers. The same amount of water was applied to both crops because of the design of the irrigation system. The low irrigation efficiency was due to the three flood irrigations of 10 ha-cm/ha each that had to be applied at the beginning of the growing season since the drip-irrigation system was inoperable due to technical problems.

A yield of 36,602 kg/ha for the drip-irrigated tomatoes compared favorably with Demonstration Farm average yields of 17,900 kg/ha and 29,800 kg/ha for flood-irrigated tomatoes in 1977 and 1976, respectively.

Salt Movement Below a Drip-Irrigation System

The irrigation efficiency, as shown in the drip irrigation of the pecan orchard, can be close to 100 percent. Salts will precipitate and be stored beneath the root zone over a long-time period. In order to investigate this problem, soil samples were taken during the second and third years of the demonstration project.

Table 50 presents the salt content of soil samples taken from flood-irrigated alfalfa and lettuce, and the drip-irrigated pecan orchard in 1977. Salinity of the soil samples on pecans varied between January and November. This was attributed to variability within the field and/or to actual changes in the salt content within the soil profile. It appeared that near the pecan trees there was a salt buildup to a depth of 1.2 meters. Farther away from the tree trunks the salt buildup was closer to the surface. This was expected due to the shape of the water front around the emitter; the greatest leaching occurred directly beneath the emitter, and less leaching occurred away from the emitter. The location of the emitters around the trees was at the same location as the sample taken at the one meter distance from the tree trunk. The salt content of the pecan orchard appeared to be higher than that encountered under the alfalfa and lettuce fields. The higher salt concentrations in the area of the drip-irrigated pecan orchard could be due to the irrigation method or soil types present. The high level of gypsum in the low layers has been encountered in other areas of the valley that were flood irrigated.

Infiltration Measurements in Canals

Deep seepage from the main and distribution canals in an irrigation system has been measured to be as much as 30-50 percent of the total flow (Rowher, 1946). It is difficult to estimate transmission losses because of the large variability associated with seepage measurements from site to site.

In studying the influence of concrete lining on seepage losses from farm ditches, Hanson (1966) reported a large variability in the transmission losses from unlined farm ditches. Losses varied from less than 1 percent of the flow to as much as 16 percent with an average loss of about 7 percent

TABLE 49. APPLIED WATER INFORMATION FOR THE DRIP IRRIGATION ROW CROP DEMONSTRATION OF TOMATOES AND PEPPERS

Irrigation Date	Total Water Applied	Application per Hectare	Rainfall	Evapotranspiration (ET) for Tomatoes	Evapotranspiration (ET) for Peppers	
	(m^3x10^3)	(ha-cm/ha)	(ha-cm/ha)	(ha-cm/ha)	(ha-cm/ha)	
Trickle Plot (.22 hectares) - Tomatoes and Peppers - Planted 4-8-77 - Harvested 8-26-77						
4-13-77	.411	18.68	-	Flood Irrigation		Seasonal field Irrigation Efficiency for Tomatoes 48.5%
4-28-77	.462	21.00	-			
5-18-77	.360	16.36	0.4			
5-26-77	.308	14.00	-			
7-01-77	.288	13.09	1.1			
7-09-77	.005	0.23	3.5			
7-11-77	.016	0.73	-			Seasonal field Irrigation Efficiency for Peppers 65.6%
7-18-77	.180	8.18	-			
7-21-77	.151	6.86	-			
8-02-77	.071	3.23	1.5			
8-08-77	.155	7.04	-			
8-14-77	.014	0.64	0.7			
8-20-77	.032	1.45	0.1			
Season Totals	2.459	111.49	7.3	57.7	77.9	

Yields:

Tomatoes	- 36602. kilograms/hectare
Hungarian wax peppers	- 29065. kilograms/hectare
Bell peppers	- 20521. kilograms/hectare
Big Jim peppers	- 20702. kilograms/hectare

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TABLE 50. SOIL ANALYSIS FOR SALT CONTENT FOR SELECTED SAMPLES, EPA DEMONSTRATION FARM, 1977

Plant Type	Sample	E.C.		pH		Saturation		Concentration*								
								Ca	Mg	Na	K	Cl		CO_3	HCO_3	SO_4
	(cm)	(mmhos)				(percent)		(meq/L)								
		Jan.	Nov.	Jan.	Nov.	Jan.	Nov.					Jan.	Nov.			
	0.0- 7.5	.92		7.73		32.5		4.24	1.48	3.84	.51	1.89		0	4.04	4.16
	7.5- 15.0	.89		7.77		29.8		4.13	1.42	3.95	.21	1.70		0	3.50	4.44
	30.0- 37.5	.82		7.85		31.1		3.16	1.24	4.17	.21	1.86		0	3.02	4.36
Alfalfa	60.0- 67.5	1.22		8.03		28.9		3.95	1.41	9.22	.26	2.96		0	3.26	8.00
	90.0- 97.5	2.31		8.03		25.6		3.76	2.92	18.28	.39	6.76		0	3.18	15.40
	120.0-127.5	1.03		8.20		23.8		2.18	.99	8.02	.19	2.42		0	1.48	7.20
	150.0-157.5	.74		8.35		22.0		1.59	.59	6.24	.14	1.98		0	2.08	3.96
	175.0-182.0	.54		8.54		25.8		.68	.38	4.59	.14	1.62		0	1.68	2.52
	0.0- 7.5	1.58		8.08		61.3		4.28	2.31	7.87	.58	4.91		0	2.18	7.60
	7.5- 15.0	1.61		7.94		56.2		4.60	2.85	7.74	.65	4.91		0	3.08	7.70
	30.0- 37.5	1.19		8.15		40.4		2.76	1.98	5.97	.45	3.29		0	2.40	5.10
Lettuce	60.0- 67.5	.88		8.29		31.9		1.81	1.47	4.75	.32	2.13		0	1.54	3.60
	90.0- 97.5	1.02		8.48		30.1		2.24	1.54	5.28	.31	2.48		0	1.54	5.00
	120.0-127.5	.61		8.35		33.8		.53	.75	4.75	.20	1.20		0	1.98	2.76
	150.0-157.5	.74		8.32		28.8		1.91	.72	5.84	.22	2.13		0	1.78	4.70
	175.0-182.0	.97		8.28		24.2		1.22	1.22	7.39	.20	2.15		0	2.46	5.08
	0.0- 7.5	1.21	3.56	7.88	7.85	50.0	35.8	1.95	1.68	8.30	1.07	3.12	16.16	0	5.50	5.00
Pecan	7.5- 15.0	1.11		7.85		50.1		2.01	1.64	7.94	.94	2.76		0	5.64	4.70
samples	30.0- 37.5	1.25	3.70	8.01	7.72	66.2	59.8	1.31	1.26	10.05	.88	4.58	17.61	0	2.58	6.10
located	60.0- 67.5	1.81	4.67	8.01	7.71	50.4	46.3	4.13	1.46	14.91	.05	6.67	11.99	0	3.38	10.60
at tree	90.0- 97.5	4.00	2.60	7.83	7.87	54.8	44.9	21.51	8.20	25.64	.60	5.08	11.28	0	.84	51.60
trunk	120.0-127.5	7.58	6.59	7.99	7.50	50.5	40.1	14.43	15.14	54.90	.79	5.62	28.54	0	1.46	73.60
	150.0-157.5	5.55		8.26		34.5		7.69	7.39	53.62	.45	19.11		0	1.46	48.80
	175.0-182.0	5.33		8.26		31.3		5.43	5.87	55.54	.47	18.23		0	1.62	44.40
Pecan	0.0- 7.5	1.27		8.02		46.1		2.94	1.56	8.86	.91	4.29		0	4.54	5.40
samples	7.5- 15.0	1.09		8.08		50.8		3.20	1.13	7.58	.75	3.48		0	3.34	5.40
located	30.0- 37.5	1.53		8.06		71.7		1.42	1.17	13.45	.36	4.16		0	2.16	9.90
.5 m	60.0- 67.5	4.25		7.88		85.0		22.14	9.12	28.83	.50	7.07		0	1.20	51.60
from	90.0- 97.5	4.41		7.85		52.3		18.38	9.91	29.68	.45	11.34		0	1.32	48.80
trunk	120.0-127.5	6.40		7.95		46.4		15.38	12.52	54.26	.54	23.16		0	1.32	60.80
of tree	150.0-157.5	5.64		8.36		35.1		6.63	6.93	55.76	.43	20.54		0	1.48	47.60
	175.0-182.0	7.17		8.21		33.0		5.93	7.97	74.04	.50	28.61		0	1.50	60.00
Pecan	0.0- 7.5	1.11	1.39	8.08	7.71	49.0	46.2	3.88	1.27	7.70	.72	3.86	4.10	0	3.48	5.80
samples	7.5- 15.0	4.34		7.91		80.1		17.77	9.81	29.68	.43	12.87		0	1.26	46.00
located	30.0- 37.5	1.40	0.67	8.12	7.82	53.7	40.1	1.57	1.19	11.15	.63	4.75	1.35	0	3.18	7.10
1 m	60.0- 67.5	2.58	0.64	7.99	7.83	85.0	39.1	5.07	3.19	21.37	.51	8.35	1.39	0	1.72	20.20
from	90.0- 97.5	1.76	1.03	8.24	8.03	30.5	24.7	4.92	1.77	13.78	.24	5.66	1.63	0	2.06	13.20
trunk	120.0-127.5	5.33	1.73	7.98	8.19	35.1	25.4	16.50	8.28	40.06	.69	21.52	1.31	0	13.60	44.00
of tree	150.0-157.5	6.72		8.21		31.9		11.89	10.40	60.37	.59	26.90		0	1.36	57.20
	175.0-182.0	1.48		8.58		23.1		.53	.86	13.68	.16	3.85		0	2.22	9.30
Pecan	0.0- 7.5	2.11	1.95	8.03	7.87	49.4	45.4	6.17	2.43	14.57	.87	7.32	6.51	0	2.86	14.20
samples	7.5- 15.0	2.20		8.14		53.6		6.15	2.41	16.01	.86	7.69		0	2.26	15.60
located	30.0- 37.5	3.71	4.36	8.00	7.80	54.5	43.2	12.73	5.10	30.06	.83	14.80	20.20	0	1.46	37.60
2.7 m	60.0- 67.5	4.91	6.52	7.84	7.70	80.9	68.7	20.47	10.37	34.44	.72	15.31	28.99	0	1.28	48.00
from	90.0- 97.5	4.44	6.36	7.97	7.58	29.8	100.7	20.33	9.75	29.12	.45	10.93	21.01	0	1.22	46.00
trunk	120.0-127.5	5.06	6.48	8.16	7.64	36.8	27.3	10.82	8.13	43.70	.47	21.38	25.89	0	1.18	38.00
of tree	150.0-157.5	3.63		8.32		28.0		4.70	4.32	34.25	.30	11.29		0	1.80	30.80
	175.0-182.0	1.41		8.45		25.5		1.16	1.08	12.68	.18	2.78		0	1.50	10.50

* Based on analysis of saturation extract samples at indicated saturation percent.

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when the turnouts were sealed. Seepage loss depends upon the type of soil and the sediment load in the water as it affects surface sealing. Other factors that affect seepage loss percentage are the velocity and flow depth at which the water moves through the canal. For a given discharge, higher velocities require less cross-sectional area and wetted perimeter through which seepage may flow, a shorter time for water to be lost by seepage, and consequently, less seepage percentage. If weeds are allowed to grow in a ditch the velocity is lower, thus increasing the flow depth, the time opportunity for seepage, and the seepage loss percentage.

Using the ponding technique, measurements of the steady-state infiltration rate ranged from 51 cm/day for a section of Walter lateral to 11.6 cm/day for a farm field ditch, and 6 cm/day for the Upper Chamberino and main distribution canal (see Table 51). Water temperature data were analyzed using the technique described by Stallman (1965). With this technique, the lower detectable limit of percolation loss is about 2 cm/day. All the measurements indicated losses greater than this amount. The temperature determinations of infiltration rate in the farm supply ditches and Upper Chamberino lateral are presented in Table 51.

Infiltration rates determined for the Upper Chamberino lateral from temperature profile measurements were greater than those determined by using the ponding technique. The increased infiltration rate could be accounted for by the fact that there was a greater head or height of water in the canal when the temperature measurements were made than during the ponding test. In the farm ditches, the ponding measurements of infiltration were greater than those determined using the temperature technique.

Using the average infiltration rate in the Upper Chamberino lateral of 12 cm/day, the present loss per 1,000 meters of canal was calculated for different flow levels and presented in Figure 28. The loss represents a small percent unless the flow becomes very low or the length of canal excessively long.

Based on an infiltration rate of 10 cm/day (the average of the two lower infiltration rates in the farm ditches), the seepage loss from the entire farm distribution system represents 1.1 percent of the applied water over the growing season. Based on the average of the two largest infiltration measurements, 47.2 cm/day, the seepage loss represents 5.6 percent of the applied water.

Drain Flow Measurements

Weekly measurements of the drain flow were made using current meters. Water samples were taken at the time that the flow measurements were made at Sites B and D (Figure 22).

As flow rate from B to D in the drains increases, electrical conductivity or salt content of the drain water decreases (Figure 29). The salt content of the drain water did not change significantly from Sites B to D. At the five percent level of probability, there was no difference in the mean flow during the growing season (April through September) between Sites

TABLE 51. INFILTRATION RATE IN THE UPPER CHAMBERINO AND FARM SUPPLY DITCH

Date	Test No.*	Location**	Method	Final Infiltration Rate (cm/day)
8-09-77	1	Upper Chamberino	Temperature	12.9
8-09-77	2	Upper Chamberino	Temperature	16.8
7-12-77	3	Upper Chamberino Drain	Temperature	13.0
10-22-76	4	Upper Chamberino	Ponding	6.0
8-26-77	5	Farm Ditch Field 4	Temperature	8.0
8-26-77	6	Farm Ditch Field 4	Ponding	11.6
10-06-76	7	Field Ditch Field 3	Ponding	43.2
11-17-77	8	Walter's Lateral	Ponding	51.2

* Locations of test sites are shown on Figure 2.

** Clay soil.

B and D for 1975 and 1976. This was due to the nonsteady-state condition of the drains. Excess irrigation water was constantly being dumped into the drains causing marked increases or decreases in flow between measurement Sites B and D. During the 1977 growing season, most of the water in the valley near the measurement drain sites was pumped water and the drain was closer to a steady-state condition during the measurement periods. The difference in flow between Sites B and D for 1977 are presented in Figure 30. During most of the growing season, the flow rate increased significantly at the five percent level of probability from Site B to Side D indicating that the farm was contributing return flow to the drain system.

Along with measurements in flow obtained with a current meter, water depths were measured at La Mesa Drain Sites B and D with water stage recorders. A rating curve was determined for the sites using the flow data. Analysis of the data indicated that the canal bottom shifted by scouring and deposits and was insufficiently stable for a rating curve of flow depth vs. flow rate to be determined for Site B. However, the rating curve for Site D was estimated to fit a straight line with a correlation coefficient of 0.9. The rating curve equation is:

$$\text{depth} = 0.0017\ \text{flow} + 0.14$$

where depth is given in meters and flow in m^3/sec.

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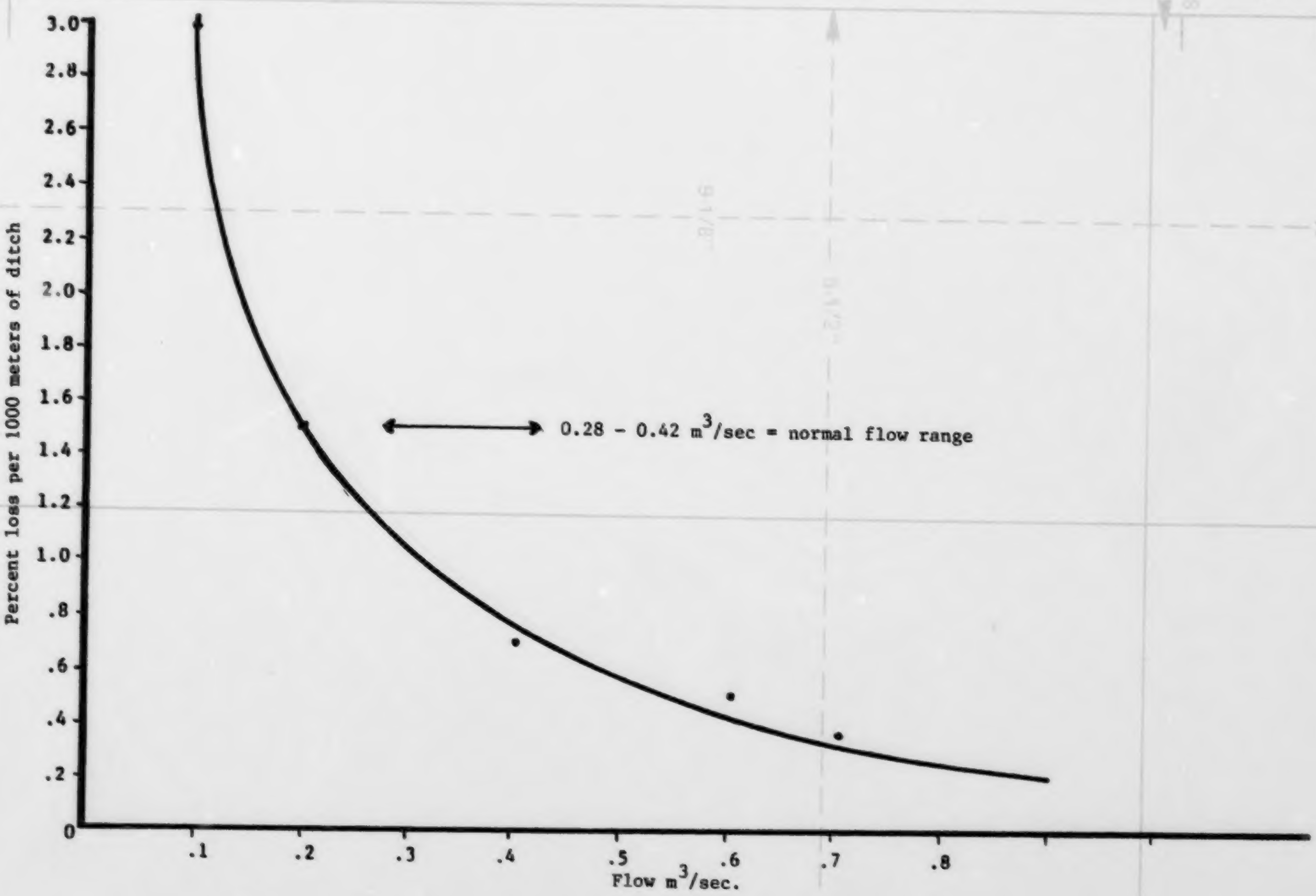

Figure 28. Seepage loss for a main distribution canal per 1000 m of length

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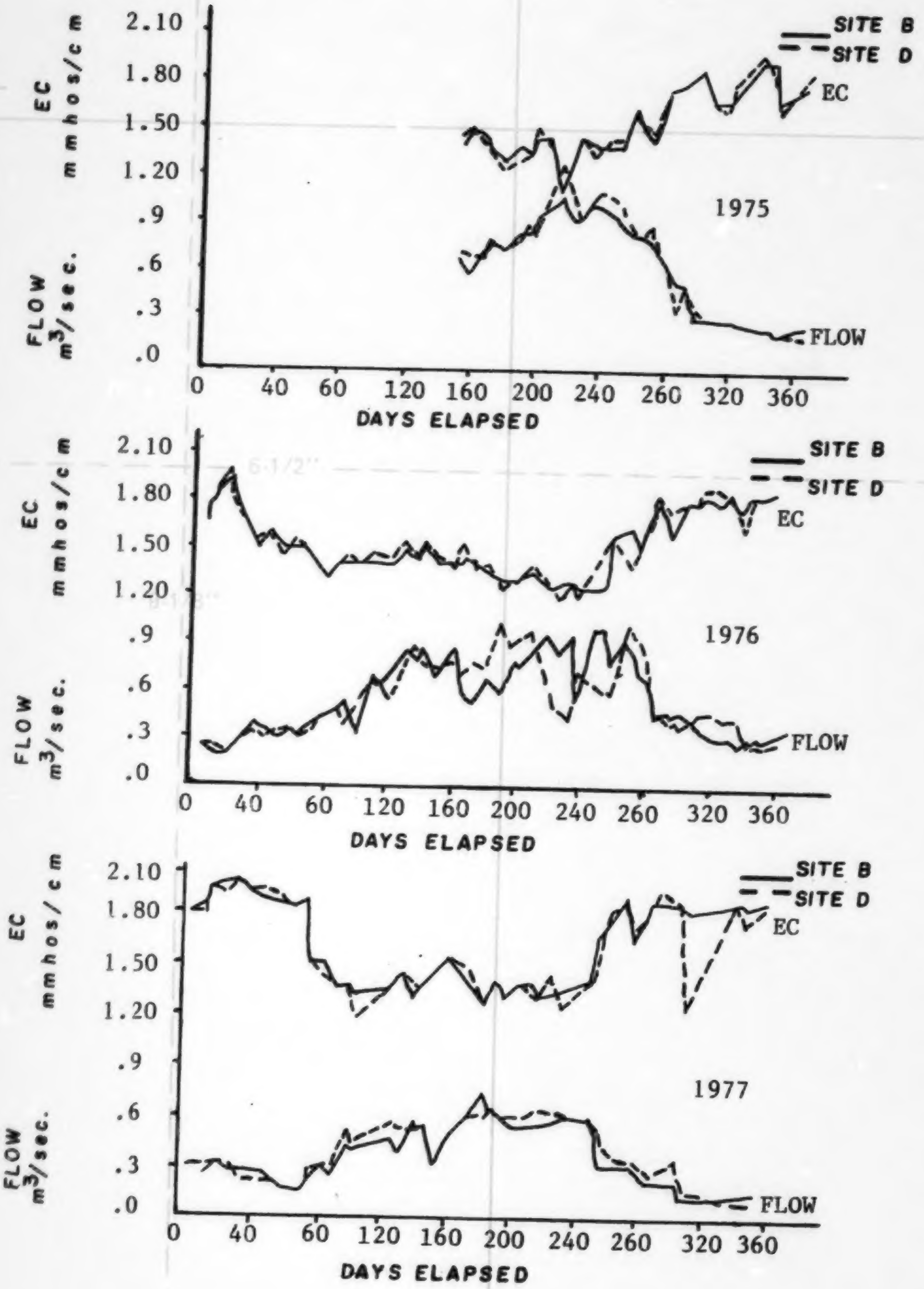

Figure 29. Flow and electrical conductivity at La Mesa Drain Sites B and D for 1975, 1976, and 1977

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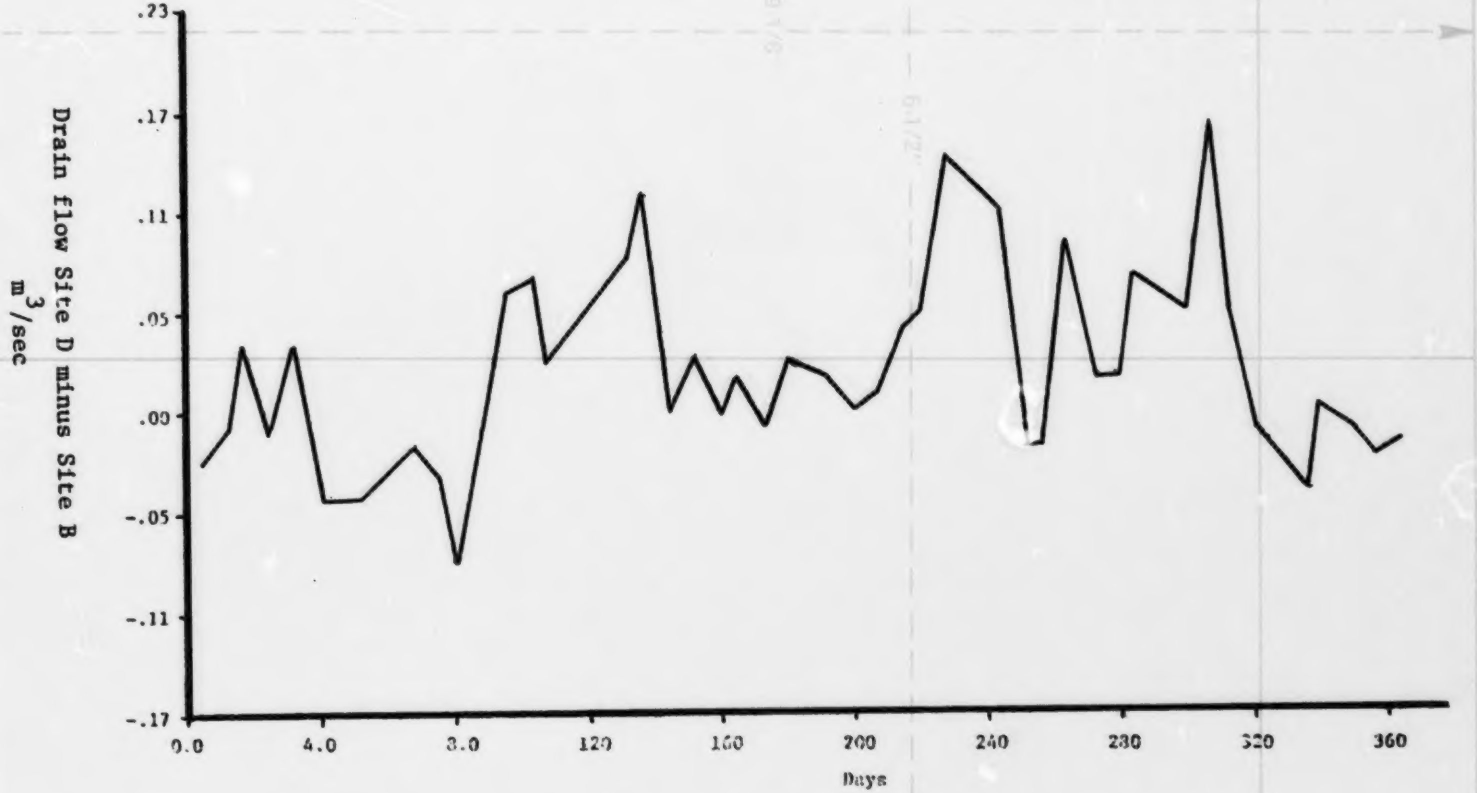

Figure 30. Difference in flow between La Mesa Drain Sites B and D.

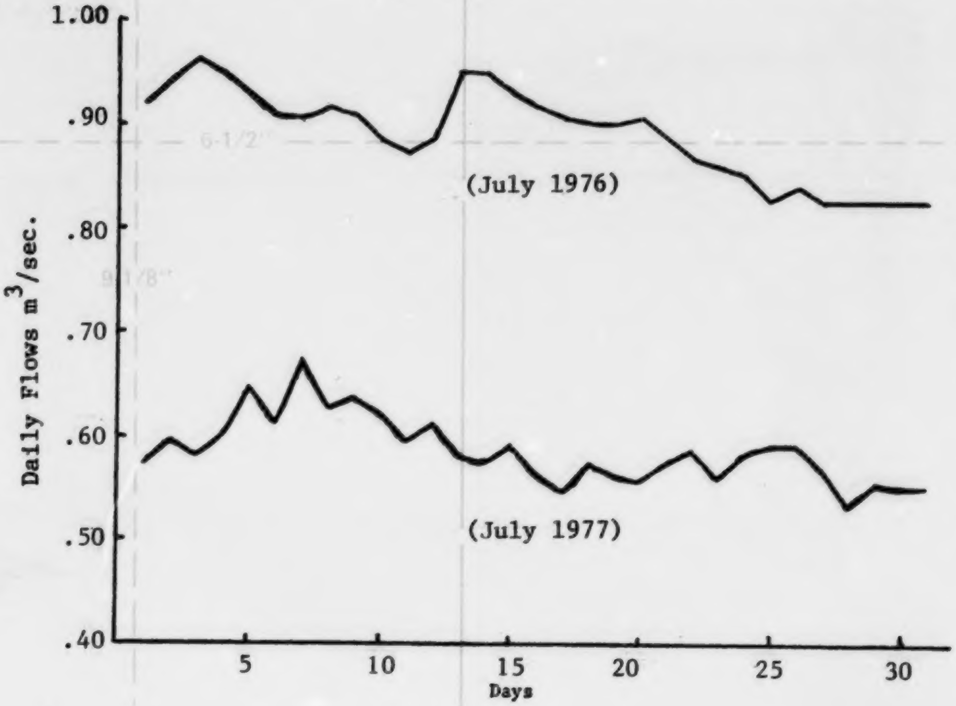

Figure 31. Daily drain flows at Site D in the La Mesa Drain.

Using this equation and the water stage levels determined with the water stage recorder, the daily flows for 1976 and 1977 were calculated for Site D (Figure 31). The daily flows fluctuated considerably during the 1976 irrigation season due to the dumping of excess irrigation water from the irrigation canals into the drainage canals. There appeared to be as much variation in the daily flows as there was in the weekly flows measured with a current meter. It has not been possible to determine the amount of fluctuation due to return groundwater flow, and how much was due to surface waste water.

Groundwater Level Fluctuations

Weekly piezometer measurements were made on a transect perpendicular to the La Mesa Drain. Several of the piezometers became plugged with soil toward the end of the study and had to be abandoned. A statistical analysis was done using a steady-state drain-flow model to try to correlate piezometer height and increase in drain flow between Sites B and D in 1977. An

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increased gradient, due to the rise in the water table from excess irrigation water, should have caused an increase in flow between Sites B and D. An analysis was conducted only on 1977 data when the increased flow was statistically significant. However, the results indicated that the system could not be statistically described at the five percent level of probability by a steady-state model applied to each measurement point. As can be observed from a plot of the water table level, the groundwater system (Figures 32 and 33) was not homogenous but contained lenses of high and low permeability. This resulted in an uneven gradient of the groundwater away from the drains. The plot of the groundwater level represents a response to both excess irrigation water and pumping from the wells in the area. During 1976, the groundwater table was low in January, February, and March and started to rise by May after water had been released into the irrigation system. This rise continued through September due to excess irrigation water. After September, the groundwater table again dropped as excess irrigation water decreased and the drains lowered. In 1977, when most of the irrigation water was supplied by groundwater, the groundwater table continued to decline throughout the year, from January through December. Due to the cropping pattern, there was less return flow although the overall farm-irrigation efficiency did not change.

Groundwater Salinity

There was a significant increase in salinity in groundwater monitoring Wells 1 and 3 between 1976 and 1977 (Table 52). The salinity in Well 2 increased in value but was not statistically significant at the 95 percent confidence level. The level of salinity in the 15-meter well was significantly different from the level of salinity in the 10-meter well which, in turn, was significantly different from the salinity level in the 6-meter well for both years. The water quality continually degraded from the deeper to the shallower wells.

The changes of individual constituents do not present a clear picture. The nitrate content did not change statistically from year 1976 to 1977, but there was a degradation of the nitrate concentration from the shallower to the deeper wells increasing to an average of 38.7 ppm. There was no significant difference between Well 2 and Well 3 at the top two depths (6 and 10 meters). Both of the top two depths were significantly different from the bottom depth.

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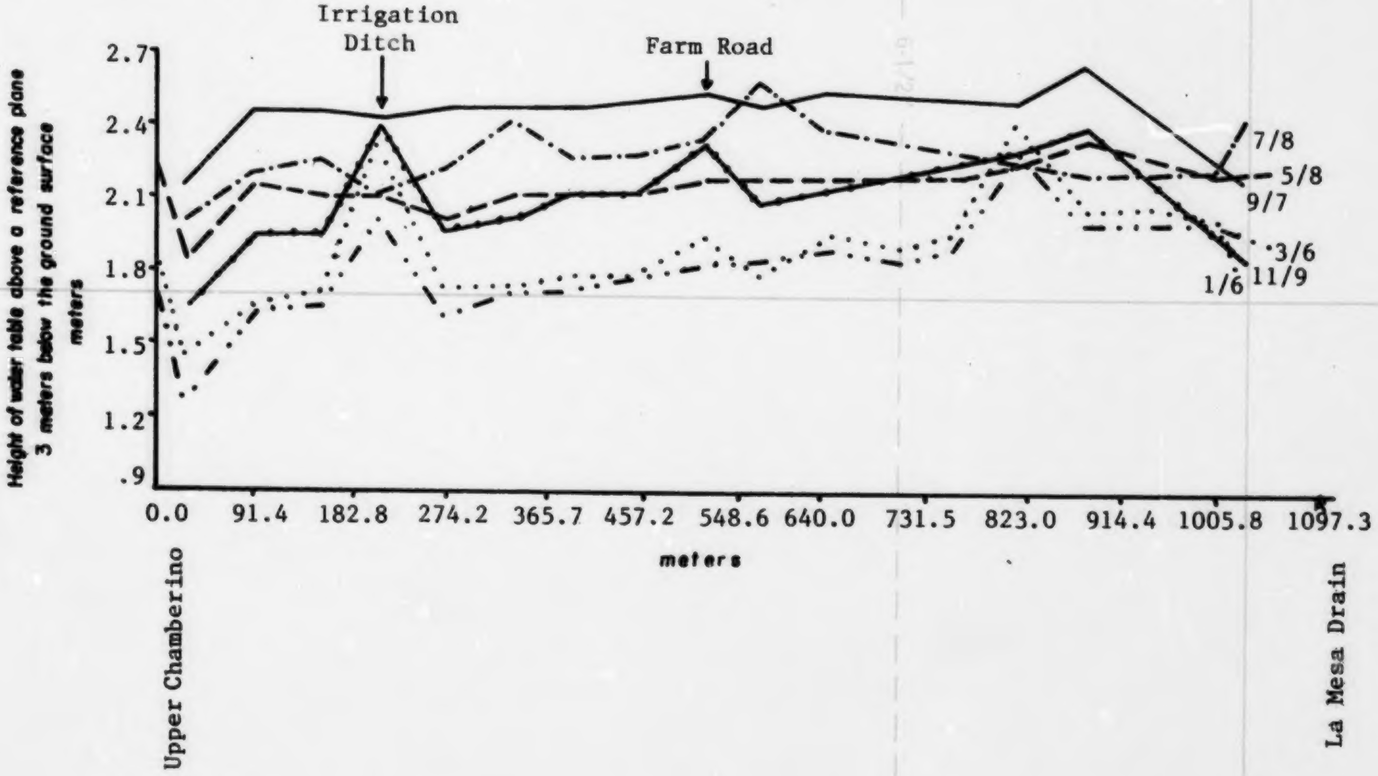

Figure 32. Groundwater height fluctuation for selected dates along a transect from the Upper Chamberino in the La Mesa Drain for 1976

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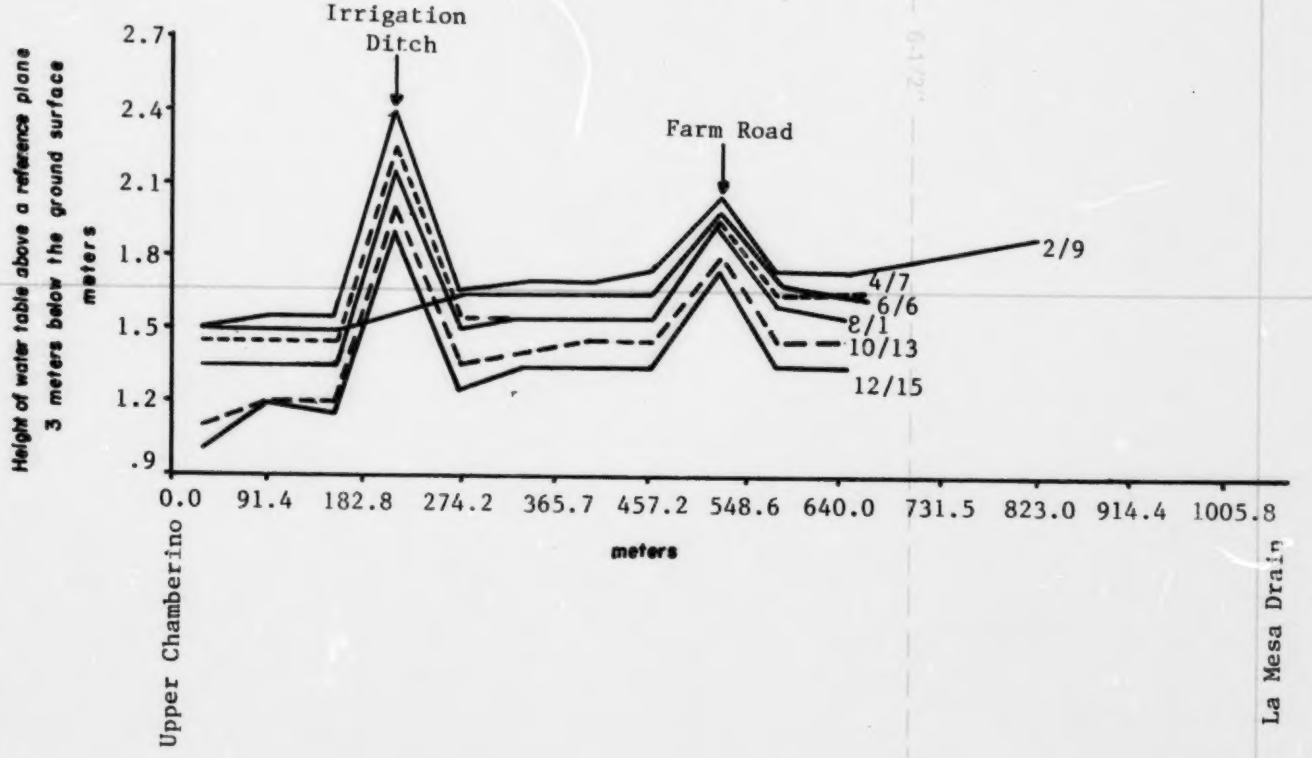

Figure 33. Groundwater height fluctuation for selected dates along a transect from the Upper Chamberino in the La Mesa Drain for 1977

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TABLE 52. A TABLE OF WATER QUALITY DATA SIGNIFICANT AT THE 95 PERCENT CONFIDENCE LEVEL FOR THREE GROUNDWATER OBSERVATION WELLS AT 15, 10, AND 6 METER DEPTHS

Well Comparison* For Yearly Mean Values	$ECx10^3$	Chemical Constituents meq/1											
		pH	Cations	Anions	Ca	Mg	Ha	K	Cl	CO_3	HCO_3	SO_4	NO_3
Well 1, 1977 Minus Well 1, 1976	.18	**			-1.4		-1.3		-0.4				
Well 2, 1976 Minus Well 2, 1977			2.4	4.5		0.5	2.2		1.56				
Well 3, 1976 Minus Well 3, 1977	-.3				-1.9		1.27						
Well 2, 1976 Minus Well 1, 1976	.5		-6.4	-5.61	3.2	-.7	-2.3		-3.2			-3.1	-36.4
Well 1, 1976 Minus Well 3, 1976	-.68		7.8	7.4	2.0	.5	-6.3		3.6			-8.0	37.7
Well 2, 1976 Minus Well 3, 1976	-.18			1.8		1.2	-4.0						
Well 1, 1977 Minus Well 2, 1977	-.3		-3.9	-3.6	2.0		-1.7		2.1			-2.3	36.7
Well 2, 1977 Minus Well 3, 1977	-.5		-4.6	-4.8		.7	-4.9	-.1	1.8		-1.1	2.0	

* Depth of Wells: Well 1 = 15 meters; Well 2 = 10 meters; Well 3 = 6 meters.

** Blanks indicate there was no significance.

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SECTION 7

ECONOMIC ANALYSIS FOR THE MESILLA VALLEY

INTRODUCTION

The economic effects of alternative water management systems for improving irrigation water applications were evaluated using four alternatives.

The alternatives evaluated were (1) the implementation of an irrigation scheduling service (ISS) into the agricultural sector of the Mesilla Valley for the period 1967-76, (2) the addition of sprinkler-irrigation for seed emergence of vegetable crops and incorporation of ISS, (3) trickle-irrigation on orchard crops in addition to ISS, and (4) the combination of sprinkler irrigation for seed emergence of vegetable crops and trickle-irrigation on orchard crops in addition to utilizing ISS.

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Three periods of time were included in each alternative. The three time periods (1967, 1973, and 1976) were chosen to represent periods of below-average, average, and above-average water supplies: (1) 1967 represented a drought condition when surface water supplies were 14,024 hectare-meters which was well below the 17 year average of 19,169 hectare-meters, (2) 1973 with a surface water supply of 22,904 hectare-meters was rather close to a 17 year average, thus representing an average water supply year, and (3) 1976 surface water supply of 25,048 hectare-meters represented an above-average supply of irrigation water (Table 3).

A two-equation mass balance hydrology model was incorporated to utilize the results of the Linear Programming models. The hydrology model utilizes the total surface and ground irrigation water applications for each of the four alternatives to determine the resulting drain flows. From these results, it was possible to determine what effect each of the alternatives had on reducing the irrigation return flows and salt load on the Rio Grande from the Mesilla Valley.

A base Linear Programming (LP) model was designed to reflect existing Mesilla Valley agricultural water management practices. The base model consisted of two parts: (1) the individual crop budgets for each of the water supply periods and (2) the LP model which served as an accounting method for the resources used and the net returns to agricultural lands and risk. The individual crop methods provided the primary data for the LP coefficients.

The alternative water management systems were analyzed via a three-

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step process: (1) revise crop budgets as required for each alternative; (2) incorporate crop budgets into the linear programming model and run the model; and (3) make comparisons to the base model. The comparisons of the revised model with the base model were made with respect to water use (surface and groundwater), total net return to land and risk for the entire Mesilla Valley, and the effect each of the alternatives had on reducing irrigation return flows.

MATERIALS AND METHODS

This portion of the study was confined to the geographic boundaries of the Mesilla Valley in the Lower Rio Grande Basin in New Mexico (see Figure 1). Only irrigated agricultural cropland in production was considered.

Crop Acreage

The 1976 cropped hectares for the Mesilla Valley were determined by evaluating the Elephant Butte Irrigation District (EBID) records and planimetering aerial photographs of the valley for 1976. The 1967 and 1973 hectares were based on 1967 and 1973 Bureau of Reclamation records for the EBID and historical trends of irrigated lands outside the EBID.

Surface and Groundwater Acreage

The cropland of the Mesilla Valley was categorized by source of irrigation water, surface and ground, to determine the total amount of water used by each source. The acreage that received surface water from the EBID was determined from Bureau of Reclamation records and a map of the Mesilla Valley furnished by the Bureau of Reclamation, El Paso Regional Office. These hectares are located in the valley floor and in many cases received supplemental water from groundwater sources (Table 53).

There are 1,940 hectares that are irrigated by groundwater only. The area which received irrigation water from groundwater sources only was determined by subtracting the surface and groundwater hectares from the total irrigated hectares in the valley for 1967, 1973, and 1976 (Table 53). Typically these hectares are located on the piedmont slopes and valley highlands and are inaccessible to surface water sources.

Irrigation Requirements

To evaluate the effects of alternative water management practices in the Mesilla Valley, the irrigation water consumptively used by the various crops and an estimate of the irrigation water actually applied were determined. These two values represented the ideal and the actual conditions, respectively, for the valley.

Consumptive Irrigation Requirements--

The consumptive-use estimates obtained from measurements on the Demonstration Farm (see Section 6) were used to determine the consumptive irri-

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TABLE 53. IRRIGATION CROP HECTARES FOR THE MESILLA VALLEY, NEW MEXICO, 1967, 1973 AND 1976

Crop	Surface and Groundwater 1967	Surface and Groundwater 1973	Surface and Groundwater 1976	Groundwater Only 1967	Groundwater Only 1973	Groundwater Only 1976
	(hectares)					
Alfalfa	4,274	3,994	4,947	621	490	425
Chile	562	1,431	1,474	--	80	120
Corn	496	352	196	32	40	--
Cotton	16,170	14,375	11,470	643	609	591
Grain Sorghum	600	741	680	38	78	98
Irrigated Pasture	632	372	383	8	264	332
Lettuce	1,411	1,327	1,200	3	--	--
Onions	805	839	864	3	--	--
Small Grains	764	1,458	3,170	127	278	353
Miscellaneous Vegetables	235	890	1,334	44	--	--
Tomatoes (Processing)	216	121	125	--	--	--
Orchards	1,781	3,659	4,602	94	45	20
Total	27,946	29,559	30,444	1,612	1,883	1,940

gation requirements (CIR) by crops. These values were compared to estimates of requirements calculated by the modified Blaney-Criddle technique to estimate evapotranspiration for 1976, 1973 and 1967 (Table 54). The results of the Blaney-Criddle calculation for 1976 were comparable to those obtained from field measurements on the Demonstration Farm. The Blaney-Criddle estimates of CIR for 1973 and 1967 were adjusted to be consistent with the 1976 Demonstration Farm measured values (Table 54) and those reported by Gelhar and Mclin (1979).

Actual Irrigation Applications--

The actual irrigation application efficiency for flood irrigation varies widely between crops. To estimate the total irrigation applications, farmers were interviewed and results from other research were used to arrive at an estimate of the amount of irrigation water (surface and groundwater) that was actually applied.

The surface water is that water supplied by the EBID from Caballo and Elephant Butte reservoirs. The amount of surface water supplied in 1967, 1973 and 1976 was obtained from Bureau of Reclamation, El Paso Division, monthly delivery records (Table 3). These deliveries were prorated to all agricultural farm lands in the Mesilla Valley even though a portion may not have received any surface water. Surface water applications were subtracted from total irrigation water requirements resulting in the measure of groundwater application by crop and time periods. The estimated irrigation water application rates by source, crop, and by year are presented in Table 54.

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TABLE 54. PER HECTARE EVAPOTRANSPIRATION AND IRRIGATION APPLICATIONS BY CROPS IN THE MESILLA VALLEY, NEW MEXICO, 1967, 1973, 1976

Crop	Evapotranspiration*			1967		1973		1976	
	1967	1973	1976	Surface	Ground	Surface	Ground	Surface	Ground
	(hectare-cm)								
Alfalfa	153.7	157.8	154.1	53	139	80	116	82	110
Chile	76.2	63.2	77.9	49	72	60	41	76	48
Corn Silage	70.0	58.0	62.0	49	75	60	43	76	43
Cotton	58.0	67.0	60.0	49	54	60	58	76	30
Grain Sorghum	60.0	50.0	54.0	49	58	60	28	76	20
Irrigated Pasture	141.6	152.2	143.8	49	119	60	121	76	95
Lettuce (spring)	71.0	70.0	67.0	25	53	22	55	20	53
Lettuce (fall)	38.0	54.0	45.0	15	46	24	62	30	41
Onions (spring)	27.0	35.0	43.0	49	59	27	53	30	69
Onions (fall)	59.0	57.0	60.0	49	52	60	40	76	28
Small Grains (winter)	56.0	49.0	64.0	49	37	33	43	47	52
Small Crains (spring)	40.0	37.0	38.0	27	42	60	3	65	--
Tomatoes	64.9	56.7	57.7	49	79	60	53	76	38
Pecans	115.0	114.0	114.0	49	88	76	59	76	59
Average	79.1	84.4	83.6	48	73	62	63	73	50

*Based on demonstration farm measurements.

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EXPERIMENTAL PROCEDURES

Linear Programming

Linear programming (LP) is a technique that is often helpful in decisions requiring a choice among a large number of alternatives. In this study, linear programming was used to account for resources used and returns from irrigated agriculture in the Mesilla Valley.

The base model which served as a proxy for evaluating the alternative water management systems was derived from base-year budgets for 1967, 1973 and 1976. These budgets were considered representative of the irrigated farm sector in the Mesilla Valley for each time period and water supply period.

The budgets for 1973 served as the typical water supply level between the two extremes of 1967 and 1976. In this model, surface water was fixed at the actual EBID farm deliveries as reported in Table 3. Groundwater pumpage was assumed to supply the difference between surface water deliveries and the total irrigation requirements. Therefore, three base LP models were developed representing the three different surface water supply periods (1967, 1973 and 1976). Twelve alternative LP models were developed representing each of the four irrigation management alternatives for each of the surface water supply periods.

After the base models were constructed, in order to analyze a given alternative, budgets and LP coefficients were revised. Each of the 14 crops were constrained to the base level acreages for the alternatives for each of the water supply periods. Therefore, changes in net returns will be due to specific water management practices.

Once the base period linear programming models were developed, various assumptions, detailed below, were made and incorporated into the base-year budgets and linear programming models to represent each of the four irrigation alternatives. The following is a description of each of the four alternatives.

Alternative I (ISS)

The first alternative was the use of irrigation scheduling service (ISS). ISS was evaluated, as were the other three alternatives, to determine what the economic effect would have been on the irrigated farming sector in the Mesilla Valley had it been implemented in 1967, 1973, or 1976. ISS is a procedure of using observed values of solar radiation, precipitation, and evaporation to determine the quantity of irrigation water required to achieve maximum crop production. The irrigation requirements vary with soil type and stage of growth of the individual crops. There were three basic assumptions incorporated into the evaluation of ISS.

The first assumption was to reduce irrigation applications. The application efficiency is typically measured by dividing farm deliveries minus tailwater plus precipitation into the cropland evapotranspiration quanitity (Walker, et al., 1977). Through the use of irrigation, applications are

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made after estimating the available soil moisture and applying the quantity of irrigation water needed to saturate the soil horizon. Applications should occur when the crop soil moisture utilization approaches the stress level for the specific crop and soil. By using ISS, the farm operator is required to plan both irrigation periods and the quantity of water to be applied. The irrigation efficiencies reported in Section 6 for the Demonstration Farm on alfalfa varied from 76 to 92 percent, cotton from 48 to 84 percent with an average of 72 percent and chile averaged 63.35 percent. Because of the wide range in irrigation efficiencies after employing ISS on the Demonstration Farm, discussions were held with the ISS contractor and other farmers using ISS. The contractor and the farmers felt that a 10 percent increase in irrigation efficiency was about average when ISS is incorporated. Walker, et al. (1977), also reported the process can reduce irrigation application by approximately 10 percent. Therefore, irrigation applications were reduced by 10 percent from the base alternative for all crops except vegetables.

The second assumption was to increase irrigation labor requirements by 15 percent. This increase in irrigation labor requirements was based on field observation of the Demonstration Farm and farms utilizing ISS in the Mesilla Valley. The increase in irrigation labor was a result of more precise irrigation application rates which required construction of additional checks and furrow borders. These types of pre-irrigation operations result from using alternative irrigation methods such as alternate row irrigations. Alternate row irrigation for row crops such as cotton and chile, is often used in heavier soils similar to those that exist in the Mesilla Valley.

The third assumption was to increase yields by five percent on all crops except lettuce and onions. This rate was estimated based on the increased efficiency of irrigation applications resulting from ISS utilization. By using ISS, plants receive water when it is most beneficial for their growth and development which results in increased yields.

The costs for ISS varied depending on level of service and geographic location. Most prices ranged from $6.18 to $14.83 per hectare for ISS (Jensen, 1977). In the Mesilla Valley, the following prices were used, based on the ISS utilized on the Demonstration Farm plus discussions with the manager of ISS company serving the Demonstration Farm: $11.12 per hectare in 1967, $13.27 per hectare in 1973, and $14.33 per hectare in 1976.

Alternative II (ISS and Sprinkler)

The second alternative evaluated was the use of ISS and sprinkler irrigation for seed emergence of vegetable crops. The use of sprinkler irrigation for seed emergence was incorporated as a fixed cost-per-hectare contract charge of $47.94 in 1967, $57.16 in 1973 and $61.78 in 1976. This procedure was followed because of the expense of purchasing an irrigation sprinkler system only for seed emergence. In addition, this is the common practice in Mesilla Valley.

There were four assumptions incorporated into the evauation of ISS and sprinkler-irrigation of vegetable crops. The first assumption was to increase the yield levels by five percent above the ISS yield levels. More uniform

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and earlier stands for vegetables can be expected when sprinkler-irrigation is used for seed emergence. The second assumption was to decrease pre-plant irrigation labor for vegetable crops by 34 percent. The 34 percent was the decrease in irrigation labor developed by Cummings and Gisser (1977), in changing from flood irrigation to a sprinkler-irrigation system. The third assumption was to decrease irrigation water applications on lettuce, onions, and tomatoes by an additional 15 percent, and chile by eight percent below that required for ISS alone.

A fourth assumption was to increase the supervision rate by approximately 10 percent for irrigation labor. The use of sprinkler for crop production required that the farm manager devote more time to regulate irrigation requirements and irrigation application rates. In utilizing sprinkler irrigation for seed emergence, it was assumed that the pre-plant flood irrigation would be replaced with two or three pre-emergence sprinkler irrigations.

The on-farm variable cost of the sprinkler system for 1976 was $0.44 per ha-cm with fixed cost being $0.38 per ha-cm, for 1973 variable cost was $0.41 per ha-cm with fixed costs being $0.35 per ha-cm, and for 1967 variable cost was $0.35 per ha-cm with fixed cost being $0.29 per ha-cm.

Alternative III (ISS and Trickle)

The third alternative was the utilization of trickle-irrigation on orchard crops. Pecans account for nearly all of the acreage in orchard crops and therefore were used as a proxy. ISS was also included. There were two additional assumptions added to the assumptions on ISS.

The first assumption was to decrease irrigation water applications on orchard crops 36 percent below that required for ISS. This was based on observations and measurements on the Demonstration Farm and from discussions with the ISS contractor. The second assumption was to decrease irrigation labor by 60 percent, but increase management by 14 percent (Cummings and Gisser, 1977). Yield levels were assumed to be maintained at the levels attainable with only ISS.

Alternative IV (ISS, Sprinkler, and Trickle)

The fourth alternative evaluated was to combine the three previously discussed alternatives (ISS on all crops, sprinkler on vegetable crops, and trickle on orchard crops) into one model. The assumptions of this model were the combination of the assumptions of the three previous alternatives.

The four linear programming models were used to estimate the effects of the alternative irrigation management systems on net returns to irrigated agriculture in the Mesilla Valley. The changes occurring from the four alternatives were incorporated into a linear programming model to demonstrate what effects they would have on water requirements and net returns to agricultural lands in the Mesilla Valley and to compare these to the base conditions. The linear programming models consisted of nine resources and 14 crop activities.

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Drain Flows

Based, in part, on the results presented in Section 5 and from Gelhar and McLin (1979), it is suggested that improvements in irrigation efficiency could be made in the Mesilla Valley without excess accumulation of salts in the upper soil profile, and without negative effects on crop yields. Improvement in the irrigation efficiency should reduce the salt load in the irrigation return flow, at least for some time. At present, it is difficult to predict how long the salt load would be reduced upon a 10 or 20 percent increase in irrigation efficiency. Assuming salt balance, it may be expected that a new equilibrium condition would be established after some time, with a lower volume of return flow at a higher concentration and the same total salt load in the return flow (Wierenga, 1980).

A simple water balance equation is used to determine irrigation drain flows. The two equations of the drain flow model are:

$$Q_f = Q_s + Q_g - Q_e \qquad (1)$$

$$Q_e = E_s Q_s + E_g Q_g \qquad (2)$$

where:

Q_f = quantity of irrigation return flow (drain flow) in hectare-cm per year

Q_s = quantity of surface water supplied to the farm gate in hectare-cm per year

Q_g = quantity of groundwater supplied in hectare-cm per year

Q_e = quantity of evapotranspiration in hectare-cm per year

E_s = farm irrigation efficiency level for surface water

E_g = farm irrigation efficiency level for groundwater

The mean EC of 1.46 mmhos/cm presented in Table 35, the milligrams per liter were calculated to be 1,057. The tons of salt in the return flows were calculated based on the data.

Budgeting

The per hectare enterprise cost and return budgets were developed for 14 crops for each of the years 1967, 1973, and 1976. These 14 crops, which represent most of the cultivated acreage in the Mesilla Valley, were: alfalfa, chile, corn silage, cotton, grain sorghum, irrigated pasture, lettuce (spring and fall), onions (spring and fall), small grains (winter and spring), tomatoes, and pecans. Tomatoes were utilized as a proxy for the miscellaneous vegetables in the valley. The budgets developed were designed to represent the base conditions in the valley with which to compare the alternative irrigation management systems.

The enterprise cost and return budgets were prepared to provide an evaluation base for the economic analysis of alternative irrigation management systems. Procedures in preparing enterprise budgets for each of the three time periods (1967, 1973, and 1976) involved the following five steps:

1. The cultural and harvest operations were those typically performed on farms for each crop in the Mesilla Valley.
2. The physical quantities per hectare for all inputs, including services such as labor and machinery hours plus seed, fertilizer, irrigation water, and other materials were obtained from survey data files for the years 1967 and 1973 and from field observations both on and off the Demonstration Farm during 1975-1976. Price data on these inputs were obtained from farm supply stores in the Mesilla Valley and from in-file reports in the Agricultural Economics Department, New Mexico State University.
3. The yields and prices farmers receive for crops were the average yields and prices farmers receive in Dona Ana County, New Mexico as reported in the New Mexico Agricultural Statistics for 1967, 1973, and 1976; from Statistical Reporting Service releases; and actual yields and prices from the Demonstration Farm. The yields utilized in the economic analysis are reported in Table 55 for the three time periods.
4. The fixed and variable machinery cost for the three periods were developed for a typical commerical farm in the Mesilla Valley. Straight-line depreciation was utilized in estimating the fixed depreciation costs. Fuel and repair costs were developed based on secondary data from Arizona and California studies as well as Demonstration Farm information (Reed, 1974 and Hawthorn and Wright (1976). Some farming operations were assumed to be performed on a custom or contract basis for those operations typically contracted.
5. The labor requirements were based on cultural operation efficiency levels in hectares per hour for hand labor and machine operators. The supervision and management rates were adapted from a study of the Navajo Indian Irrigation Project (Sweetser, et al., 1976). The wage rates are reported in Table 56. The supervision charge was computed as follows: hours of direct labor (by type) x supervision factor (by crop) = supervision charge (dollars per hectare). The supervision factors are presented in Table 57.

The fixed and variable cost per hectare were summed and then subtracted from gross returns in order to obtain net contributions per hectare to land and risk.

RESULTS AND DISCUSSION

The economic and water use effects of four alternative irrigation water management systems will be compared to the existing irrigation water manage-

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TABLE 55. BASE YEAR YIELD AND YIELD INCREASES FROM IRRIGATION SCHEDULING SYSTEM (ISS), SPRINKLER IRRIGATION, AND TRICKLE IRRIGATION BY CROP IN THE MESILLA VALLEY, 1967, 1973, AND 1976

		Base Yield			ISS Yield			Sprinkler Yield			Trickle Yield		
Crop	Unit	1967	1973	1976	1967	1973	1976	1967	1973	1976	1967	1973	1976
Alfalfa	MT/ha	11.2	11.7	13.5	11.8	12.3	14.2						
Chile													
Green	MT/ha	11.2	12.3	13.0	11.8	13.0	13.7	12.4	13.6	14.4			
Red	Kg/ha	415	459	482	435	483	506	457	506	532			
Corn Silage	MT/ha	38.1	38.2	37.1	40.1	40.0	38.9						
Cotton													
Lint	Kg/ha	694	589	807	728	618	847						
Seed	Kg/ha	1,156	982	1,344	1,213	1,032	1,412						
Grain Sorghum	Kg/ha	4,481	4,705	5,041	4,705	4,940	5,293						
Irrigated Pasture	Kg/ha	571	762	762	600	800	800						
Lettuce													
Spring	cartons/ha*	1,433	1,334	1,062	1,433	1,334	1,062	1,504	1,401	1,116			
Fall	cartons/ha*	1,235	1,186	1,433	1,235	1,186	1,433	1,296	1,245	1,504			
Onions													
Spring	MT/ha	35.9	34.3	44.9	35.9	34.3	44.9	37.7	35.9	47.2			
Fall	Mt/ha	31.4	32.6	37.6	31.4	32.6	37.6	33.0	34.2	39.5			
Small Grains													
Winter	Kg/ha	3,584	4,033	4,257	3,764	4,234	4,469						
Spring	Kg/ha	3,808	4,369	3,921	3,999	4,589	4,117						
Tomatoes	MT/ha	26.9	28.1	29.9	28.3	29.5	31.4	29.7	30.9	32.9			
Pecans	Kg/ha	1,456	1,456	1,456	1,529	1,529	1,529				1,529	1,529	1,529

* A carton is equal to approximately 21 Kg.

TABLE 56. WAGE RATES BY WATER SUPPLY PERIOD FOR THE MESILLA VALLEY, NEW MEXICO, 1967, 1973 AND 1976

Water Supply Period	Wage Rate (dollars)
Below Average (1967)	
Irrigation Labor	1.00 per hour
Machine Labor	1.25 per hour
Average (1973)	
Irrigation Labor	1.67 per hour
Machine Labor	2.07 per hour
Above Average (1976)	
Irrigation Labor	2.00 per hour
Machine Labor	2.50 per hour

TABLE 57. SUPERVISION FACTORS BY TECHNOLOGY FOR THE MESILLA VALLEY, NEW MEXICO, 1967

Technology	Field Crops	Vegetable Crops	Orchard Crops
Base			
Irrigation and General Labor	1.80	2.60	2.60
Machine Labor	.90	1.80	1.80
ISS			
Irrigation and General Labor	2.00	2.85	2.86
Machine Labor	.90	1.80	1.80
Sprinkler			
Irrigation and General Labor	--	2.86	--
Machine Labor	--	2.00	--
Trickle			
Irrigation and General Labor	--	--	3.00
Machine Labor	--	--	2.00

ment practices. Three periods of time were included which represent below-average, average, and above-average surface-irrigation water supply.

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Base Model

The base model was designed to simulate the Mesilla Valley irrigated farming sector without the alternative water management systems being implemented. The net returns per hectare to land and risk by crop for each of the water supply periods are presented in Table 58. Some crops, such as small grains were included for crop rotational purposes.

The water use coefficients per hectare for the base period are presented in Table 54 by water supply period. The average irrigation water application rate per hectare during 1967 was 121 cm or with approximately 60 percent being supplied from groundwater sources (Table 54). The average per hectare irrigation application rate for 1973 was 125 cm. The water use was divided almost equally between ground and surface water. During 1976, groundwater only supplied about 40 percent (1,634,151 ha-cm) of the total irrigation water supply of 123 cm per hectare (Table 59). Nearly all of the differences in groundwater pumpage between the three years were due to the availability of surface water supplies.

The results of the base models for the water supply periods are presented in Table 59. The net return to land and risk for 1967 was estimated at approximately $4.3 million, for 1973 at approximately $5.7 million, and for 1976 at approximately $14.9 million (Table 59).

The quantity of irrigation return flow (drain flow) for the base model was determined by incorporating the irrigation water quantities derived from the LP model into the hydrology model. The irrigation efficiencies for the hydrology model were assumed to be 65 percent for the base period. The drain flows for the base water supply periods were 1,226,673 hectare-cm in 1967, 1,285,224 hectare-cm in 1973, and 1,280,409 hectare-cm in 1976. The salt load from the irrigation return was estimated to be 129,659 tons in 1967, 135,848 tons in 1973, and 135,339 tons for 1976.

The net returns to agricultural land and risk and irrigation labor requirements were determined from the base model solutions. The LP model was constrained only by the individual crop hectares for the three water supply periods. The respective coefficients for the three water supply periods represent the irrigated farming sector of the Mesilla Valley without the implementation of alternative irrigation management practices.

The base period results (water use, returns, and costs) served as the foundation from which each of the four alternative water management systems were compared.

Alternative I (ISS)

The results of ISS implementation into the Mesilla Valley irrigated farming sector consisted of (1) revisions to the base period budgets and (2) modifications of the base LP model with regard to the assumptions made previously. Crop budgets were designed to represent the irrigated farming sector of the Mesilla Valley after the implementation of ISS. The net returns to land and risk per hectare by crop for each of the water supply

TABLE 58. PER HECTARE NET RETURNS TO LAND AND RISK BY CROP, WATER SUPPLY PERIOD, AND ALTERNATIVE MANAGEMENT PRACTICES, MESILLA VALLEY, NEW MEXICO

Alternative	Net Return to Land and Risk Capital per Hectare													
	Alfalfa	Chile	Corn Silage	Cotton	Grain Sorghum	Irrigated Pasture	Lettuce (spring)	Lettuce (fall)	Onions (spring)	Onions (fall)	Small Grains (winter)	Small Grains (spring)	Tomatoes	Pecans
	(dollars per hectare)													
Base Period														
1967	-34.25	-57.28	-37.98	150.11	-8.23	-55.44	2,080.70	802.22	203.76	-790.96	-54.00	-21.94	172.18	28.09
1973	108.10	324.19	-23.55	66.42	66.34	132.84	6,678.77	-44.40	241.78	160.42	.59	48.85	120.34	79.22
1976	266.17	535.41	-14.16	508.45	45.84	-33.93	-675.36	4,958.49	321.52	-658.14	51.03	24.04	956.73	353.75
Irrigation Scheduling Service (ISS)														
1967	-33.70	-25.40	-37.88	166.77	-5.81	-55.94	2,066.81	788.49	189.50	-805.31	-54.68	-21.87	193.80	59.28
1973	115.69	359.77	-19.92	65.46	72.10	141.51	6,661.80	-60.14	223.05	142.95	.69	51.79	144.50	132.00
1976	236.62	590.76	-7.73	551.57	51.82	-30.66	-696.69	4,938.42	299.41	-678.58	59.06	28.44	1,026,37	423.08
ISS Plus Sprinkler														
1967	-34.05	-182.28	-38.13	166.67	-6.00	-56.29	2,121.79	781.20	153.67	-890.68	-54.76	-21.99	132.42	59.43
1973	114.95	312.65	-20.19	65.09	71.95	140.62	6,956.98	-102.50	192.78	114.01	.39	51.82	79.89	131.95
1976	242.75	513.34	-6.23	552.90	52.51	-25.43	-756.63	5,161.60	291.30	-739.02	61.58	28.44	1,010.16	426.51
ISS Plus Trickle Irrigation														
1967	-32.05	-165.18	-37.04	167.38	-5.16	-54.53	2,043.77	766.79	163.65	-831.26	-54.29	-21.40	144.83	-155.77
1973	117.54	314.21	-19.27	66.34	72.50	143.49	6,641.39	-79.07	199.65	119.22	1.38	51.79	97.65	-56.66
1976	237.86	484.98	-7.41	551.84	51.94	-29.58	-716.28	4,920.06	277.14	-701.48	59.57	28.44	980.18	244.78
ISS Plus Sprinkler and Trickle Irrigation														
1967	-32.44	-181.54	-37.26	167.23	-5.36	-54.89	2,122.31	781.67	154.14	-890.26	-54.39	-21.52	133.11	-155.32
1973	116.80	313.12	-19.57	65.97	72.35	142.62	6,957.67	-101.68	193.50	114.36	1.06	51.82	80.38	-56.29
1976	236.45	511.44	-7.78	551.54	51.79	-30.89	-759.20	5,159.87	288.04	-740.15	58.98	28.44	1,008.70	225.15

TABLE 59. RESULTS OF THE LINEAR PROGRAMMING MODEL BY WATER SUPPLY PERIOD AND ALTERNATIVE MANAGEMENT PRACTICE, MESILLA VALLEY, NEW MEXICO

Management Practice	Net Return to Land and Risk	Water Use		Operating Capital	Labor
		Surface	Ground		
	dollars	ha/cm	ha/cm	dollars	dollars
Below Average Water Supply (1967)					
Base	4,308,069	1,420,398	2,145,163	16,159,095	3,688,138
Alternative I (ISS)	4,647,000	1,420,398	1,779,711	16,676,535	3,854,447
Alternative II (ISS and Sprinkler)	4,516,395	1,420,398	1,741,237	17,404,210	4,038,917
Alternative III (ISS and Trickle)	4,106,632	1,328,389	1,788,452	17,132,778	4,275,538
Alternative IV (ISS, Sprinkler and Trickle)	4,135,114	1,328,762	1,749,952	17,536,656	4,388,520
Average Water Supply (1973)					
Base	5,673,523	1,944,988	1,994,571	23,539,678	5,233,434
Alternative I (ISS)	5,944,278	1,942,624	1,603,588	24,275,248	5,480,801
Alternative II (ISS and Sprinkler)	5,867,852	1,942,624	1,552,339	25,082,492	5,687,271
Alternative III (ISS and Trickle)	5,107,868	1,660,423	1,723,651	24,905,306	6,104,260
Alternative IV (ISS, Sprinkler and Trickle)	5,142,024	1,660,359	1,672,328	25,553,250	6,151,487
Above Average Water Supply (1976)					
Base	14,870,614	2,352,550	1,634,151	30,952,121	7,504,410
Alternative I (ISS)	16,244,729	2,342,030	1,243,985	31,863,852	7,827,818
Alternative II (ISS and Sprinkler)	16,294,017	2,323,037	1,202,898	32,921,128	8,155,317
Alternative III (ISS and Trickle)	14,710,688	1,989,728	1,393,891	32,686,593	8,577,834
Alternative IV (ISS, Sprinkler and Trickle)	14,995,777	1,970,558	1,352,430	33,475,578	8,636,567

periods are presented in Table 54. Net returns per hectare utilizing ISS were increased for all crops except lettuce and onions (Table 54).

The total surface and groundwater requirements for the incorporation of ISS are presented in Table 59. The average per hectare irrigation requirements under the ISS alternative was assumed to be 90 percent of the base model for three years. Surface-irrigation water was unchanged in 1967; however, in 1973 and 1976, surface-irrigation water would have been reduced by 0.1 percent (2,364 hectare-cm) and 0.5 percent (10,520 hectare-cm) (Tables 60 and 61). Groundwater saved through ISS was more substantial at 365,542, 390,983, and 390,166 hectare-cm for 1967, 1973, and 1976, respectively. This groundwater savings amounted to from 17.0 to 23.9 percent. Thus, ISS achieves savings in groundwater pumpage for all three supply levels, whereas, surface water savings were small and might vary with the surface water supply level (Tables 60 and 61).

The net return to land and risk for 1967 was estimated at approximately $4.65 million, up 7.9 percent from the base model. The net return to land and risk for 1973 was estimated at approximately $5.94 million, up 4.8 percent, and for 1976 at approximately $14.87 million, up 7.2 percent (Tables 59 and 62). Labor and operating capital costs increased about 3 percent due to the inclusion of ISS (Table 59). These costs have increased over the years, also. However, crop price increases and yield increases have more than offset these costs within each time frame. However, it must be noted that it is possible that net returns from one year to the next decrease depending on relationships between price levels, cost levels, and yields.

The reduction in drain flow from the incorporation of ISS ranged from 30 percent in 1967 to 36 percent in 1976 (Table 63). The drain flows for the ISS water supply periods were 861,221 hectare-cm in 1967, 891,877 hectare-cm in 1973, and 879,723 hectare-cm in 1976. The reduction in salt load to the Rio Grande was estimated to be 38,628 metric tons in 1967, 41,577 metric tons in 1973, and 42,352 metric tons in 1976 (Table 63).

Alternative II (ISS and Sprinkler)

The use of ISS on all crops and sprinkler-irrigation for seed emergence of vegetable crops was the second alternative irrigation water management system evaluated. The results of the ISS and sprinkler model implementation in the Mesilla Valley irrigated farming sector consisted of (1) revisions to the ISS vegetable crop budgets and (2) modification of the ISS LP model.

The budgets were designed to represent the irrigated farming sector of the Mesilla Valley after the implementation of ISS and sprinkler-irrigation for vegetable crop seed germination. The net returns per hectare to land and risk for each of the water supply periods are presented in Table 59. The incorporation of sprinkler-irrigation for vegetable crop seed germination resulted in adjustments in the net returns to land and risk per hectare for only chile, lettuce, onions, and tomatoes.

The total surface and groundwater requirements for the incorporation of ISS and sprinkler-irrigation are presented in Table 59. The average per

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TABLE 60. RELATIVE CHANGE IN IRRIGATION WATER USE BY SOURCE, TIMING, AND ALTERNATIVE MANAGEMENT PRACTICE, MESILLA VALLEY, NEW MEXICO

Management Practice	Change in Surface Water from Base			Change in Ground Water from Base		
	1967	1973	1976	1967	1973	1976
	Hectare-cm			Hectare-cm		
Alt. I	0	-2,364	-10,520	-365,542	-390,983	-390,166
Alt. II	0	-2,364	-29,513	-403,926	-442,232	-431,253
Alt. III	-92,009	-284,565	-362,822	-356,711	-270,920	-240,260
Alt. IV	-91,636	-284,629	-381,992	-395,211	-322,243	-281,721

TABLE 61. PERCENT CHANGE IN IRRIGATION WATER USE BY SOURCE, TIMING, AND ALTERNATIVE MANAGEMENT PRACTICE, MESILLA VALLEY, NEW MEXICO

Management Practice	Percent Change, Surface			Percent Change, Ground Water		
	1967	1973	1976	1967	1973	1976
Alt. I	0	-0.1	-0.5	-17.0	-19.6	-23.9
Alt. II	0	-0.1	-1.3	-18.8	-22.2	-26.4
Alt. III	-6.5	-14.6	-15.4	-16.6	-13.6	-14.7
Alt. IV	-6.4	-14.6	-16.2	-18.4	-16.2	-17.2

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TABLE 62. NET RETURNS TO LAND AND RISK BY TIME PERIOD AND ALTERNATIVE MANAGEMENT PRACTICES, MESILLA VALLEY, NEW MEXICO

Management Practice	1967 ----Change from Base--- Dollars	1967 Percent	1973 ----Change from Base---- Dollars	1973 Percent	1976 ----Change from Base---- Dollars	1976 Percent
Alt. I	338,931	7.9	270,755	4.8	1,374,115	9.2
Alt. II	208,326	4.8	194,239	3.4	1,423,403	9.6
Alt. III	-201,437	-4.7	-565,655	-10.0	-159,926	-1.1
Alt. IV	-172,955	-4.0	-531,499	-9.4	125,163	0.8

TABLE 63. ESTIMATED DRAIN RETURN FLOW AND SALT LOAD BY TIME PERIOD AND ALTERNATIVE MANAGEMENT POSITION, MESILLA VALLEY, NEW MEXICO

Management Practice	Evapotranspiration	Drain Return Flow	Percent Change From Base	Salt Load	Reduction in Salt Load from Base
	ha-cm	ha-cm		metric tons	metric tons
Base -- 1967	2,338,888	1,226,673	--	129,659	--
Alternative I		861,221	-30	91,031	38,628
Alternative II		822,747	-33	86,964	42,695
Alternative III		777,953	-37	82,230	47,429
Alternative IV		739,826	-40	78,200	51,459
Base -- 1973	2,654,335	1,285,224	--	135,848	--
Alternative I		891,877	-31	94,271	41,577
Alternative II		840,628	-35	88,854	46,994
Alternative III		729,739	-43	77,133	58,715
Alternative IV		678,352	-47	71,702	64,146
Base -- 1976	2,706,292	1,280,409	--	135,339	--
Alternative I		879,723	-31	92,987	42,352
Alternative II		819,643	-36	86,645	48,685
Alternative III		677,328	-47	71,594	63,745
Alternative IV		616,696	-52	65,185	70,154

hectare irrigation water requirement when sprinkler-irrigation for seed emergence was incorporated with ISS for 1967 was estimated to be 107 cm, which was about 89 percent of the requirement for the base model (Table 59). The water savings over ISS was about one percent. Surface-irrigation water was unchanged in 1967; however, in 1973 and 1976, surface-irrigation water would have been reduced by 0.1 percent (2,364 hectare-cm) and 1.3 percent (4,257 ha-cm) (Tables 60 and 61). Groundwater saved through this alternative was more substantial at 403,926, 442,232, and 431,253 hectare-cm for 1967, 1973, and 1976, respectively. This groundwater savings amounted to from 18.8 to 26.4 percent. Thus, the addition of a sprinkler for vegetable germination achieved savings in groundwater pumpage for all three supply levels, whereas, surface water savings were relatively small and might vary with the surface water supply level (Tables 60 and 61). The groundwater saved for this alternative was approximately 1.8 percent for 1967, 2.6 percent for 1973, and 2.5 percent for 1976 over ISS alone.

The net return to land and risk for 1967 was estimated at approximately $4.65 million, up 4.7 percent from the base model. The net return to land and risk for 1973 was estimated at approximately $5.94 million, up 3.4 percent from the base model, and for 1976 at approximately $16.29 million, up 9.6 percent from the base model (Tables 59 and 62).

Labor and operating capital costs increased about 7 percent due to adding a sprinkler for vegetable seed germination to the ISS alternative costs within each time frame.

The reduction in drain flow from the incorporation of ISS and sprinkler ranged from 33 percent in 1967 to 36 percent in 1976 (Table 63). The drain flows by water supply periods for the ISS and sprinkler alternative were 822,747 hectare-cm, in 1967, 840,628 hectare-cm in 1973, and 819,643 hectare-cm in 1976. The reduction in salt load to the Rio Grande was estimated to be 42,695 metric tons in 1967, 46,994 metric tons in 1973, and 48,685 metric tons in 1976 (Table 63).

Alternative III (ISS and Trickle)

The use of ISS on all crops and trickle-irrigation for orchard crops was the third alternative irrigation water management system evaluated. The results of the ISS and trickle model implementation in the Mesilla Valley irrigated farming sector consisted of (1) revisions to the ISS orchard crop budgets and (2) modification of the ISS LP model.

The budgets were designed to represent the irrigated farming sector of the Mesilla Valley after the implementation of ISS and trickle-irrigation on orchard crops (pecans). Over 95 percent of the orchards in the Mesilla Valley are pecans. Net returns to land and risk per hectare for pecans were reduced about $173 in 1967, $23 in 1973, and $129 in 1976 with the incorporation of trickle-irrigation. The individual crop budgets containing the two modifications for improvement of irrigation water management (ISS and trickle) provided the primary data for the revision of the base LP coefficients for Alternative III.

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The total surface and groundwater requirements for the incorporation of ISS and trickle-irrigation for orchards are presented in Table 59. The average per hectare irrigation water requirement when trickle-irrigation for orchards was incorporated with ISS in 1967 was estimated to be 105 cm, which was about 87 percent of the requirement for the base model (Table 59). Surface-irrigation water would have been reduced by 6.5 percent (92,009 hectares-cm), in 1967, 14.6 percent (284,565 hectare-cm) in 1973 and 15.4 percent (362,822 hectare-cm) in 1976 (Tables 60 and 61). Groundwater saved through ISS and trickle-irrigation for orchards was more substantial at 356,711 hectare-cm for 1967. However, in 1973 and 1976 surface water savings exceeded groundwater savings and amounted to from 6.5 to 15.4 percent, respectively. Thus, the combination of ISS and trickle-irrigation for orchards achieved substantial savings in both surface and groundwater pumpage for all three supply levels (Tables 60 and 61). The surface water saved for this alternative was approximately 1.8 percent for 1967, 14.5 percent for 1973, and 14.1 percent for 1976 over ISS alone. The groundwater savings were less than ISS for all three time periods ranging from 0.4 percent in 1967 to 9.2 percent in 1976 (Table 61).

The net return to land and risk for 1967 was estimated at approximately $4.11 million, down 4.7 percent. The net return to land and risk for 1973 was estimated at approximately $5.11 million, down 10.0 percent; and for 1976 at approximately $14.71 million, down only 1.1 percent from the base model (Tables 59 and 62).

Labor and operating capital costs increased about 8 percent due to adding trickle-irrigation to the ISS alternative (Table 59). The crop price and yield increases did not offset these increased costs within each time frame.

The reduction in drain flow from the incorporation of ISS and trickle ranged from 37 percent in 1967 to 47 percent in 1976 (Table 63). The irrigation return flows for the water supply periods were 777,953 hectare-cm in 1967, 729,739 hectare-cm in 1973, and 677,328 hectare-cm in 1976. The reduction in salt load to the Rio Grande was estimated to be 47,429 metric tons in 1967, 58,715 metric tons in 1973, and 63,745 metric tons in 1976 (Table 63).

Alternative IV (ISS and Sprinkler and Trickle)

The use of ISS on all crops, sprinkler-irrigation for seed emergence of vegetable crops and trickle-irrigation on orchard crops was the fourth alternative irrigation management alternative evaluated. The results of the ISS, sprinkler, and trickle model implementation in the Mesilla Valley irrigated farming sector consisted of (1) revisions to the ISS vegetable crop budgets and the ISS orchard (pecan) crop budgets; and (2) modification of the ISS LP model.

The budgets were designed to represent the irrigated farming sector of the Mesilla Valley after the implementation of the ISS, sprinkler, and trickle irrigation techniques. The incorporation of ISS, sprinkler, and trickle irrigation resulted in modifications to both the vegetable and orchard crops. The individual crop budgets containing the three modifications for improvement of irrigation water management (ISS, sprinkler, and trickle) provided the primary data for the revision of the base LP coefficient for Alternative IV.

The total surface and groundwater requirements for the incorporation of ISS and trickle-irrigation for orchards are presented in Table 59. The average per hectare irrigation water requirement when sprinkler-irrigation for vegetable seed emergence and trickle-irrigation for orchards was incorporated with ISS in 1967 was estimated to be 104 cm, which was about 86 percent of the requirement for the base model (Table 59). Surface-irrigation water use would have been reduced by 6.4 percent (91,636 hectares-cm) in 1967, 14.6 percent (284,629 hectare-cm) in 1973 and 16.2 percent (381,992 hectare-cm) in 1976 (Tables 60 and 61). Groundwater saved through this alternative was more substantial at 395,211 hectare-cm (16.2 percent) for 1967 and 322,243 hectare-cm (18.4 percent) in 1973. However, in 1976, surface water savings exceeded groundwater savings (Table 61). Thus, the combination of ISS, sprinkler, and trickle-irrigation systems achieves substantial savings in both surface and groundwater pumpage for all three supply levels. (Tables 60 and 61). The surface water saved under this alternative was approximately 6.4 percent for 1967, 14.5 percent for 1973, and 14.9 percent for 1976 when compared to ISS. The groundwater savings under this alternative were less than those of ISS for 1973 and 1976 (from 0.4 percent in 1973 to 6.7 percent in 1976), but greater than ISS in 1967 with a 1.4 percent saving (Table 61).

The net return to land and risk for 1967 was estimated at approximately $4.14 million, down 4.0 percent; 1973 approximately $5.14 down, 9.4 percent; 1976 approximately $15.14 million, down only 0.8 percent from the base model (Tables 59 and 62).

Labor and operating capital costs increased about 10 percent due to adding a sprinkler for vegetable seed germination and trickle-irrigation alternative (Table 59). The crop price and yield increases did not offset these increased costs in 1967 and 1973 but did increase in 1976.

The reduction in drain flow from the incorporation of ISS, sprinkler and trickle ranged from 40 percent in 1967 to 52 percent in 1976 (Table 63). The drain flows for the water supply periods were 739,826 hectare-cm in 1967, 678,352 hectare-cm in 1973, and 616,696 hectare-cm in 1976. The reduction in salt load to the Rio Grande was estimated to be 51,459 metric tons in 1967, 64,146 metric tons in 1973, and 70,154 metric tons in 1976 (Table 63).

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